REPRODUCTION, NEST SITE SELECTION, AND NEONATAL BEHAVIOUR IN A NORTHERN PERIPHERAL POPULATION OF BLANDING'S TURTLE (*EMYDOIDEA BLANDINGII*)

Katherine Lorraine Standing
B.Sc., Queen's University, Kingston, Ontario, 1994

Thesis
submitted in partial fulfillment of the requirements for
the Degree of Master of Science (Biology)

Acadia University, Wolfville, Nova Scotia
Fall Convocation 1997

National Library
of Canada

Acquisitions and
Bibliographic Services

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale
du Canada

Acquisitions et
services bibliographiques

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

0-612-23702-8

Table of Contents

List of Tables

List of Figures.

List of Appendices

Abstract.

The Blanding's turtle population in Nova Scotia is restricted to the southwestern interior in and around Kejimkujik National Park. This is the warmest region in the province, and it is thought that the restricted distribution reflects thermal constraints on reproduction. As well, differences in this population's nesting ecology, as compared with populations in more southern parts of the species' range, are thought to be in response to thermal constraints. This population suffers from high levels of egg failure, even in the absence of predation, and the results of this study show that reproductive success is constrained compared with that in populations elsewhere. Females reach sexual maturity in their late teens or early twenties. Females produce a maximum of one clutch of 4 to 15 eggs per year, and most turtles reproduce less than annually. Nesting occurs from early June to early July, and peaks in the latter part of June. Nests are constructed on southern slopes, only a few meters from water. Though substrates used are more coarse than reports from elsewhere, there is no evidence of substrate selection by females. However, nest sites are significantly warmer than randomly chosen sites on the nesting beaches. The extended egg incubation intervals (82 to over 100 days) and developmental abnormalities observed in this population suggest that reproductive success of Blanding's turtles in Nova Scotia is compromised by low temperatures. Reproductive success may be further reduced depending on the overwintering success of neonates. Upon emergence from the nest, hatchlings do not seek water or vegetation cover, they do not follow slope or a consistent compass bearing, and they do not follow nestmates. Evidence suggests that hatchlings in this population may use aquatic and terrestrial hibernacula. These behaviours are inconsistent with reports from elsewhere.

Glossary of abbreviations and terms

aCS: Absolute clutch size determined by counting all eggs as they were deposited.

Carapace: the dorsal shell of a turtle.

CL: Carapace length (maximum).

Clutch size: refers to the number of eggs per nest.

COSEWIC: The Committee on the Status of Endangered Wildlife in Canada.

CW: Carapace width (maximum).

eCSh: Clutch size estimated from hatching and excavation records.

eCSn: Clutch size estimated during nesting.

Emergence: refers to emergence from the nest; 'natural emergence' excludes excavation data.

Nesting season: the interval in which nest construction was observed.

O-E_1: the time elapsed (days) from oviposition to the emergence of the first hatchling.

O-E_2: the time elapsed (days) from oviposition to excavation of live hatchlings.

O-E_3 : the time elapsed from oviposition to the first signs of pipping.

Oviposition: egg laying.

PL: Plastron length (maximum).

Plastron: the ventral shell of a turtle.

PW: Plastron width measured along the anterior suture of the femoral scute.

Recruitment: The number of new individuals added to the population; in this thesis 'recruitment' is used only in the context of the addition of turtles into the adult, breeding population.

Reproductive potential: at the individual level this means either: 1) the number of eggs an individual can produce in a season; this includes both individual clutch size and intra-annual clutch frequency (annual reproductive potential) (Gibbons 1982, Gibbons 1968a); or 2) the number of eggs produced by an individual over a lifetime (lifetime reproductive potential); at the population level this term incorporates the mean annual reproductive potential (*i.e.* the number of eggs produced annually in the population) and the number of sexually mature females in the population. The method used by Graham (1979) in which the mean annual reproductive potential (individual) is multiplied by the estimated number of adult females in the population neglects the clutch frequency variation among females and therefore overestimates the population's reproductive potential.

Reproductive success: estimates egg and hatchling survivorship within the population. Herman *et al.* 1995 included this aspect in their definition of reproductive potential; I distinguish between reproductive potential and success for simplicity, only.

Scute: Individual scales of the plastron or carapace; margins of adjacent scutes are called sutures. Marginal scutes comprise the outermost ring of scutes of the carapace and are used in the notching systems.

Vitellogenesis: The production of egg yolk proteins (vitellogins), and consequent yolking of follicles, through the mobilization of fat reserves. While vitellogenesis is regulated by hormones, primarily estrogen (Ho *et al.* 1982), hormonal and reproductive cycles in turtles are regulated by temperature (Ewert 1985, Ganzhorn and Litch 1983).

Geological terms:

(Compton 1985, Townbridge (Ed.) 1962, Sneed and Folk 1958, Krumbein 1941).

Sorting: Describes the degree of similarity or uniformity of particle size in a sample. Visual key in Compton (1985).

Sphericity: Decribes the extent to which a particle shape resembles a sphere categories include: Blade (low sphericity), roller (medium sphericity) and spheroid (high sphericity). This term is not synonymous with 'roundness'. Visual key in Compton (1985).

Roundness: Describes the curvature of a particle's edges, or the smoothness of corners. Visual key in Compton (1985).

Acknowledgements

I thank World Wildlife Fund Canada for financial support; Parks Canada for permission to use the study area and unpublished records, and for providing logistical support; the members of my advisory and examining committees, Drs. S. Boates, S. Bondrup - Nielsen, R. J. Brooks, R. Morrison, P. Taylor for their advice and criticisms, and a special thanks to Dr. D. Toews, for his patience while reading the final revisions; Dr. I. Spooner for his help and advice with the geology component of this project; Dr. D. Ryan for providing statistical expertise in design and analysis, and for his assitance in the field. For their communications and insight, I also thank B. Butler, G. Packard, T. Power and S. Bleakney. I am indepted to the following for their help collecting and analysing data: E. Alcorn, R. Charlton, J. Clarke, C. Drysdale, C. Frail, T. Gilbertson, M. Hardman, G. Herman, P. Hope, S. Hope, D. Hurlburt, R. MacFarlane, N. McMaster, J. McNeil, S. and L. Mockford, E. Muntz, R. Nicholas, D. Oickle, S. Ogrady, T. Ramey, T. Turliuk, T. Whidden and D. Whynot. Thanks also to Ron and Anna for more than I can express. I am especially indepted to Ian Morrison for his moral support and assistance in and out of the field, for his help in the design and execution of this project, and for his tireless enthusiam, friendship and encouragement. Finally, I thank my supervisor and mentor, Dr. T. Herman. Thank-you for everything.

For my mother, Elisabeth McAskill.

Chapter 1.

Nesting ecology of Blanding's turtles (*Emydoidea blandingii*) in Nova Scotia.

In 1993, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Nova Scotia population of Blanding's turtle (*Emydoidea blandingii*) 'Threatened'. This assessment was based on the population's small size and geographic isolation, as well as the unstable age structure, the apparent absence of immature turtles, and low recruitment into the breeding population (Herman *et al.* 1995). In response to COSEWIC's designation, a recovery plan was drafted for this population (Herman *et al.* submitted). This document outlines research and management required for recovery and emphasizes the need for a greater understanding of the life history, in particular the reproductive biology, of this population.

To achieve an understanding of the life history of any long-lived species, including Blanding's turtle, the acquisition of long-term data is crucial. Although data from the Nova Scotia population are available from as early as 1953, when the species[1] was first reported in the province (Bleakney 1958), early research efforts were cursory and unsystematic, and most records were anecdotal. Only in 1987 was the first intensive, multi-year study of demography, distribution and reproductive biology of this Blanding's turtle population initiated (Power 1989).

Power (1989) suggested that the nesting season is later and more compressed, and that reproduction is more constrained in Nova Scotia than elsewhere. Also, he confirmed that turtles[2] in this population exhibited some

---

[1] At the time, the species was known as *Emys blandingi.*

[2] Unless otherwise specified 'turtle' and 'turtles' mean *Emydoidea blandingii;* when referring to other turtle species the bi-nomial and common names are provided.

unusual behaviours as compared with those elsewhere in the range. For instance, in Nova Scotia Blanding's turtles nest primarily in gravel substrates, and disproportionately nest on beaches; elsewhere in the range, they nest inland and predominantly in sand or soil. Herman *et al.* (submitted) proposed that the divergence in nesting behaviour is an adaptive response to environmental constraints at the northern edge of the species' distribution, suggesting that lakeshore beaches have suitable microclimates for egg incubation. Although his data support the contention that egg failure is higher in Nova Scotia than elsewhere, Power's sample was small and the study too brief (2 seasons) to generalize confidently about reproductive success at the population level, particularly for such long-lived, iteroparous organisms (Howard 1979).

To supplement Power's findings, annual surveys of Blanding's turtle nesting activity were integrated into Kejimkujik National Park's[3] resource management protocol. Though considerable data were collected between 1988 and 1993 (Morrison 1993, 1992, Herman and Parks Canada unpublished records), no attempt was made to integrate or interpret these data. By 1993, when the Blanding's turtle was declared threatened in Nova Scotia, sizable gaps remained in our understanding of this population's life history and reproductive biology. To rectify this, a three year study was initiated by the Centre for Wildlife and Conservation Biology (Acadia University) and World Wildlife Fund Canada (Endangered Species Recovery Fund). The intentions were to provide additional and more accurate data on reproduction, and to investigate aspects of this population's ecology that remained to be studied in detail, specifically, neonatal behaviour and the characterization of nest sites.

---

[3] The 'Park' refers to Kejimkujik National Park, N.S.

The objectives of this thesis are threefold: first, to present data of the reproductive characteristics and early life-history of Blanding's turtles in Nova Scotia (Chapters 1 and 2); second, to investigate the postulate presented by Herman *et al.* (1995) and Power (1989) that Blanding's turtle reproduction is constrained in Nova Scotia (Chapter 3); and third, to examine whether temperature is the primary factor constraining reproduction and limiting the distribution of this population (Bleakney 1958) (Chapter 3).

This chapter summarizes our current knowledge of the reproductive biology of Blanding's turtles in Nova Scotia. Although the emphasis is placed on data collected during this study (1994 - 1996), historical records are integrated into the discussion to improve the interpretive value of the study.

Methods

Study site

This study was conducted in Kejimkujik National Park, Nova Scotia, Canada (44° 15'- 44° 30' N, 65° 00'- 65° 30' W) (Figure 1) in 1994, 1995 and 1996 (May 1 to October 31). Most techniques used in this study were consistent with those described by Power (1989), and all conformed to the Blanding's turtle monitoring programme protocol established in 1989 by the Park's resource management officers (Morrison, pers. comm.).

General protocol

As part of the Park's ongoing Blanding's turtle monitoring programme all previously unidentified turtles encountered during the study period were captured, sexed, assigned a notch code (Power 1989), measured, weighed, aged[4] and released at the point of capture. Measurements and age impressions of

---

[4] Impressions of scute annuli were made using dental impression plaster. It is assumed that each annulus represents one year's growth, and by counting the rings a minimum age can be determined for the turtle.

numerous previously identified (*i.e.* notched) turtles were also collected. To minimize stress, turtles were measured only once between 1994 and 1996. The following measures were recorded with Vernier calipers: maximum straight-line carapace length (CL), maximum carapace width (CW), maximum straightline plastron length (PL), and plastron width (PW) (measured along the anterior suture of the femoral scute) (Power 1989) (Appendix A). Weights were recorded to the nearest 1.0 g using a Pesola® spring balance, and adult females were palpated for oviducal eggs.

Protocol (1994 - 1996)

Beginning in early June, nesting patrols were conducted on beaches and roadways identified by Power (1989) as major nesting centres for Blanding's turtles. Other areas within the Park were also surveyed, but less intensively. Nesting patrols began between 1800 hrs and 2030 hrs, and continued until the last female had completed nesting, or until no turtles remained on the beach. Most observers walked along the beach, although some paddled by canoe. Hand-held flashlights and head-lamps were used for illumination. If no turtle activity was observed by 2200 hrs patrols were terminated. Nesting patrols were concluded in the last week of June or in early July. In 1996, automated Hobo ® temperature loggers were used to record spring water temperature in both brooks frequented by Blanding' s turtles during the summer, and in shallow coves used by females prior to nesting. Probes were placed in the water at a depth of 10 cm and temperature was recorded every 48 minutes from early May until the end of the nesting season.

The following data were recorded for each nesting turtle: date, location, time at first observation, time at which nest construction began, time at which egg laying began and ended, clutch size, when nest covering began, and the time at which the nesting sequence was completed (*i.e.* when the female had finished covering and camouflaging the nest) (Appendix B). Whenever possible, nesting turtles were identified by their notch code. Incidental observations of female turtle behaviour, and of predation and disturbance of turtles and nests were also recorded.

Absolute clutch size (aCS) was determined for many nests, by counting all the eggs as they were deposited. Sometimes, however, oviposition was observed only in part or not at all, and clutch size was estimated. I distinguish between the two clutch size estimates as follows: (1) if oviposition had begun, all eggs visible within the cavity were counted, and subsequently deposited eggs were added. The total is the clutch size estimated during nesting, or eCSn; or (2) when oviposition was not observed, the number of hatchlings accounted for during emergence was added to the number of un - emerged[5] hatchlings (alive and dead), and unhatched eggs uncovered during nest excavation. The total is the clutch size estimated during hatching, or eCSh (Appendix C).

Most nesting females were allowed to complete the nesting sequence before nests were screened. However, because of logistic constraints, it was sometimes necessary to interrupt a female in the latter stages of nest burying. In such instances an observer approached the turtle, gently lifted her from the site and replaced her on the beach approximately 10 m to one side of the nest; most turtles continued the motions of burying before returning to the water. As a precaution against turtles returning to 'nest' despite no longer being gravid (*i.e.* turtles risking predation and exhaustion), they were interrupted

---

[5] 'un -emerged-hatchlings' are those that had completely or partially emerged from the egg, but that had not emerged from the nest cavity.

only after the cavity had been completely filled, and the female had spent at least 20 minutes camouflaging the site.

A screened box[6] was placed over each nest to guard against predation (Power 1989). The box frame was placed in a shallow trench dug around the nest. The nest was centered and the wooden frame was secured with large rocks. Protected nests were assigned a number according to the sequence in which they were laid, and this number was used in the hatchling notching system (Appendix D). The boxes also served as pens for emergent hatchlings, thereby facilitating the collection of emergence data.

Beginning in September, nests were monitored regularly to check for hatchlings. The date of emergence was recorded for each hatchling. Three measures of incubation time were used: (1) the time elapsed (days) from oviposition to the emergence of the first hatchling ($O\text{-}E_1$); (2) the time elapsed (days) from oviposition to excavation of live hatchlings ($O\text{-}E_2$) (if $O\text{-}E_1$ was not available); and (3) the time elapsed from oviposition to the first signs of pipping (if $O\text{-}E_1$ and $O\text{-}E_2$ were not available (1996 only)).

The following measurements were recorded for each hatchling: maximum carapace length (CL), maximum carapace width (CW), and maximum plastron length (PL). Measures were recorded to the nearest 0.1 mm using Vernier calipers. Developmental abnormalities were recorded (Appendix E). Hatchlings were weighed to the nearest 0.1 g on a digital balance, notched and released at the nest site.

In 1994, six hatchlings were raised at Acadia University for use in a genetics study (Mockford 1996) and were released in spring 1995 in the Park as part of a radio-tracking study of young, headstarted turtles (McMaster 1996). In

---

[6] Frame dimensions: 10cm X 50cm X 50cm. The top was covered with 1 inch hardware cloth.

1994 and 1995, over 100 hatchlings were included in a study of the early post-emergence behaviour of neonates (Chapter 2, McNeil 1996).

Once natural emergence appeared to have ceased, nests were excavated to determine hatching and emergence success. Unhatched eggs, dead and live un - emerged hatchlings[7] were recorded and it is assumed that any inconsistencies between aCS and emergence and excavation records represent naturally emerged hatchlings that escaped from beneath the screened boxes. However, hatchlings neither seen nor handled are not listed as 'hatchlings emerged' (Appendix C) and were excluded from percent emergence calculations. All excavated live hatchlings were measured, notched and released using the aforementioned techniques; body size measures (*i.e.* only CL, CW and PL) of some dead hatchlings were included in calculations.

In 1996, because emergence was late and nest excavation was necessary for another aspect of this study, all nests were excavated by October 16 regardless of whether emergence had begun. The unhatched eggs were transported to Acadia University and incubated indoors in buckets filled with moist sand. Emergence and body size data were recorded.

The following techniques were used to characterize the nest sites. With a tape measure and compass, the distance and orientation to nearest water and dense vegetation (distances measured along the beach surface) were recorded for each nest. Nest slope was measured by placing a clinometer on a 50 cm^2 flat board that was centred on the nest; at the same time, nest aspect was measured with a compass. To characterize the substrate in which turtles nest in Nova Scotia, photographs were taken of the surface substrate of nests

---

[7] Hatchling refers to all turtles that emerged partially or completely from the egg, regardless of whether they emerged from the nest, or were dead or alive upon excavation. Un-emerged hatchlings are those that had not emerge from the nest.

sites and 'test pits' (*i.e.* sites where Blanding's were observed digging, but that they abandoned) throughout the nesting beaches in 1996 (Appendix F). In 1996, nest sites were excavated (50 cm^2 (surface area) X 15 cm (depth)), and the substrate dried and sieved.

Results

Migration toward the nesting centres by adult, female turtles was observed prior to the nesting season. In 1995, the earliest sighting of an adult female was June 13, when female 0-1 was collected along a roadway, radio-tagged and released (Morrison, pers. comm.). This turtle was tracked approximately 3 km as she followed a southward, overland route to her nesting location. She followed the road, about 50 m into the woods (Turliuk, pers. comm.), and ultimately nested near the location at which, in previous years, she has been observed nesting (Herman, pers. comm.). On June 6, 1996, a gravid female was seen 'wandering around' on the Eelweir road (Muntz, pers. comm.) Gravid females were also sighted in the brooks adjacent to the major nesting centres (*i.e.* Atkin' s and Heber Meadow brooks). Presumably these females were migrating to the nesting beaches, although nesting was confirmed for only 3 of these turtles ((10-2), (9-11) and (3-1)).

Nesting season

The nesting season is defined as the interval in which nest construction was observed, and, unlike in Power' s (1989) report, it does not include the time of female migration to and from the nesting centres. According to these criteria, nesting seasons of 1994, 1995 and 1996 were: June 11 - 25, 1994; June 16 - 29, 1995; and June 12 - July 5, 1996 (Table 1, Figure 2). Although no nests or signs of nest predation were observed, the 1994 nesting season may have extended into early July, since female 11-2 was observed digging a nest cavity on Glode Island on July 2, and an unidentified female was observed engaged in nesting related activities on July 3 and July 5.

The peak in nesting activity was estimated each year as the day on which the most nests were successfully protected. Consistently, this occurred in the last 2 weeks of June (Table 2, Figure 2).

Nesting behaviour

In the area of Atkin' s brook, female Blanding's turtles congregated in a cove (an unnamed cove behind Atkin' s beach) a few weeks before the onset of the nesting season. Turtles basked aerially during the day on a prominent, exposed rock in the cove. Aerial basking began in mid morning (prior to 0930 hrs) and lasted until early afternoon (ca. 1300 hrs) when the rock became shaded. Turtles frequently repositioned themselves on the rock, repeatedly entering and exiting the water. When the rock became shaded (ca. 1300 hrs) turtles entered the water, and floated and swam along the bank and in sphagnum-rich shallows. Although painted turtles (*Chrysemys picta*) and snapping turtles (*Chelydra serpentina*) of undetermined sex were seen in this cove, neither male, nor juvenile Blanding's turtles were observed. Once the nesting season was over female Blanding's turtles were no longer observed in this cove.

A similar pattern was observed at all major nesting centres. That is, each year, female Blanding's turtles congregated in sheltered coves and bays adjacent to nesting centres prior to the onset of the nesting season. Arrival at these areas usually preceded an individual's nest construction by several days. On sunny days, turtles basked on prominent, exposed rocks and logs. Turtles vacated these areas a few days after having completed nesting. The coves at

Atkin' s and Heber Meadow beaches were warmer than the nearby brooks (Atkin's brook and Heber Meadow brook) prior to, and during the nesting season (Figures 3a, 3b). However, the cove used by gravid females near Peter Point nesting beach was not warmer than the open water (Figure 3c). All three coves, unlike adjacent brooks and open water, have exposed basking sites such as rocks or logs.

In the early evening, females left the coves and swam or walked to the nesting beaches. If approaching the nesting beach from the water, turtles periodically raised their head and looked toward the beach; then, they either swam along the length of the beach, or emerged onto the beach. Once on the beach, females began 'searching' for an appropriate nest site. Searching was characterized by walking around, repeatedly pausing, and looking along the beach and toward the water. Turtles meandered on the beach, sometimes for more than an hour (*e.g.* June 30, 1996: Appendix B), before beginning to dig a nest cavity or abandoning the beach.

While searching, some females engaged in 'sand sniffing' in which females moved substrate with the front feet and pressed the nose into the disturbed area. Females dug holes up to 3 cm deep with the front legs, and either repositioned themselves and continued digging with their hind legs, or abandonned the site. At times, females engaged in sand-sniffing for nearly 2 hours (*e.g.* at Peter Point, female 0-1 was seen sand-sniffing from 1950 hrs to 2140 hrs on June 16, 1996).

Once a site was selected, females faced up-slope (most often away from water) and, digging with hind feet, alternating between left and right, excavated a deep (ca. 12 cm), flask-shaped cavity. Eggs were deposited into the cavity, and the nest was covered with substrate.

After completing nest construction females returned to the water. Many turtles were seen searching or attempting to nest on several occasions before nest construction was successful.

Although most turtles were encountered between 2000 hrs and 2200 hrs while searching or digging, some were seen searching as early as 1700 hrs. All observed nests were constructed in the evening and were under construction by 2159 hrs. Females took 24 to 178 minutes (mean = 104 mins.) to dig the nest cavity (Appendix B) before beginning to lay eggs. Oviposition started shortly after the cavity was completed. Oviposition lasted from 4 to 46 minutes, and was prolonged on cooler evenings. Turtles began covering the nest within a few minutes of having completed ovipositing.

Turtles often took more than an hour, and in some cases close to 2 hours, to bury eggs and camouflage the nest (mean = 63 minutes, n = 28, SD = 30). Most nests were completed between 2100 hrs and midnight, although, in 1995, a female was observed camouflaging her nest at 0202 hrs. This turtle was finally interrupted by observers.

The nesting interval (from the time digging began until the turtle walked away from the nest) varied among turtles, but usually lasted about 2.5 hrs (max. 5.1 hrs). When the time spent searching was included, in some cases, the nesting sequence lasted nearly 6 hours. Since no entire nesting sequence (from the time searching began until the turtle returned to the water after having nested) was observed, these results underestimate the time required for nesting.

Nest sites and beach fidelity

Most females nested within a few meters of water (mean for 46 beach nests = 4.46 m, SD = 1.86), and on slopes from 2.5 - 10.0 degrees (Figure 4). Nest were non-randomly ($P < 0.001$) distributed on southwesterly slopes (Figure 5). Most nests were within 5 m of dense vegetation (*i.e.* the forested beach edge) (mean = 2.80 m, SD = 2.03, n = 49). Surface substrate was characterized from photographs (Appendix F) and determined to be well to very poorly sorted, well to sub - rounded, blade, roller or spheroid-shaped pebbles and cobbles (Compton 1985, Townbridge 1962, Sneed and Folk 1958, Krumbein 1941)[8]. Sieving analyses of nesting substrate revealed that Blanding's turtles in Nova Scotia nest in a wide variety of substrates[9] but predominantly in coarse materials (Figure 6).

The beaches used were adjacent to Atkin's and Heber Meadow brooks, and on Glode Island and near Peter Point; turtles also nested inland along road shoulders, and in a gravel borrow pit (> 200 m from water). Also, although no nest was found, a gravid female was observed searching on Indian Point beach. The beaches with the highest concentration of turtle nests were Glode Island, Atkin's beach (I) and Heber Meadow beach (II) (Tables 3a, 3b and 3c).

Of the 15 females that nested in multiple years, eleven (73.3%) returned to the same beach (Table 3a and 3b). While most females that used different beaches returned to the same general area (*e.g.* alternating between Glode Island and Atkin's beach), one turtle (female 8,0-9) moved from Atkin's beach (1995) to Heber Meadow beach (II) (1996) (ca. 2 km).

Heber Meadow beach (I), which was historically important for nesting (Power 1989, Park records), appears to have been abandoned. Despite regular nesting patrols, Blanding's turtles were not observed searching or digging on

---

[8] See Glossary of abbreviations and terms.

[9] For a description of the Udden-Wentworth scale for the classification of grain size and texture see Fritz and Moore 1988.

Heber Meadow beach (I) after 1994. The female that nested at Heber Meadow beach (I) in 1994 nested at nearby Heber Meadow beach (II) in the following years.

Body size and age at maturity

Two turtles aged 5 years (1995, McMaster 1996) grew 0.88 cm and 1.0 cm (CL) over the course of the following year. One turtle of 17 years (1995, McMaster 1996) grew 0.8 cm (CL) in one year. Growth data suggest that growth is slow and this population has an extended juvenile stage (Figures 7a, 7b).

Only two previously unidentified, mature female turtles were encountered during this study. It is assumed that these were primiparous, that is, new recruits into the breeding population. Female 8-1,10 was the smallest mature female recorded nesting in this study (PL 17.7 cm). The other, female 9-3,11, was mid-range in size (Appendix A). Based on scute ring counts, in which it is assumed that only one growth annulus is deposited each year, female 9-3,11 was estimated to have been 19 years old when she first nested in 1995. No growth ring data were available for female 8-1,10.

Female fecundity and reproductive potential

Twenty-eight nesting turtles were identified between 1994 and 1996. Of the 15 that nested in multiple years, nine (60%) nested in three consecutive years (Table 3a), and six (40%) nested in 2 of 3 years (Table 3b). Thirteen turtles (46.4%) were observed nesting only once (Table 3c). Though additional females were identified while engaged in nesting-related activities, only those known to have produced a clutch were included in the analysis of female fecundity.

Clutch size (aCS) ranged from 4 to 15 eggs (Appendix C), and was fairly consistent within individuals among years (Table 3a, 3b). Mean clutch size was 10.3 eggs ($n = 37$, $SD = 2.4$); this was determined using only aCS. Among individuals there was no apparent trend of increases or decreases in clutch size (aCS) among years. The relationship between female body size (PL) and clutch size (max. aCS for an individual) was not significant at $\alpha = 0.05$ ($0.457 < r_{2, 13}$, $P > 0.05$) (Figure 8, Appendix A).

Incubation and emergence

Incubation time ($O\text{-}E_1$) varied among nests and between years (Table 4). In 1994, mean $O\text{-}E_1$ for 11 nests was 94.5 days ($SD = 11.4$); in 1995, mean $O\text{-}E_1$ for 12 nests was 90.1 days ($SD = 6.3$); and in 1996, mean $O\text{-}E_1$ for 2 nests was 107 days ($SD = 0$). Incubation time in nests for which $O\text{-}E_1$ was not available is defined as the number of days elapsed from oviposition to the excavation of live hatchlings ($O\text{-}E_2$). This ranged from 93 to 128 days (Table 4).

In 1996 some nests were excavated before hatching had begun. One nest that had been flooded for two days, and likely saturated for an additional 4 days, was excavated on September 20. The eggs hatched a few days later. Other clutches excavated on October 8, 1996 continued incubating indoors, and hatched between November 12 and November 28, 1996. The longest recorded incubation time from oviposition to pipping ($O\text{-}E_3$) was 137 days in 1996 (Table 3). These hatchlings took several days, in some cases over a week, to emerge from eggs. All had large yolk sacs, and appeared weak, lethargic and edematous; most died before having completely emerged from the egg.

Natural emergence (*i.e.* occurring in the field) began September 6, 1994 and September 13, 1995. It lasted until mid-October in both years. In 1996, natural emergence was late, and did not begin until October 2. The latest natural emergence occurred between October 24 - 25, 1995 (Morrison pers.

comm.).

Emergence within nests was mostly asynchronous (*i.e.* occurring over several days), spanning 2 to 11 days. In some cases active hatchlings remained for several days within the nest cavity from which other hatchlings had already emerged.

Hatchlings

The mean dimensions of hatchling Blanding's turtles measured in this study were: CL = 32.9 mm (n = 281,SD = 1.8); CW = 29.9 mm (n = 281, SD = 2.19); PL = 29.2 mm (n = 281, SD = 2.3); Weight = 8.1 g (n = 270, SD = 1.06).

Many hatchlings emerged from the nest with incompletely resorbed yolk sacs. The size of the protuberance varied within and among nests, and between years ranging from a slight swelling to the size of a pea. In 1996 many of the hatchlings that emerged late (and ultimately died) had yolk sacs approximately 1 cm in diameter.

Hatching success

In the first two years, 93.3% of successfully protected clutches were productive (*i.e.* produced at least one live hatchling), although only 1 productive nest was 100% successful in each year (Appendix C). The complete failure of one nest each in 1994 and 1995, was due to causes other than predation and flooding. Between 1994 and 1995 15 - 22% of eggs failed to hatch, and less than 75% of eggs produced live hatchlings that naturally emerged from the nest ((62.9% in 1994 and 70.7% in 1995) Appendix C). Between 2.5% (3/119 in 1995) and 6.8% (7/103 in 1994) of hatchlings were dead upon excavation in the first 2 years.

Productivity in 1996 was considerably lower than in the previous two years with only 50% (11/22) of nests producing live hatchlings (Appendix C).

Most egg failure was attributed to flooding since at least 9 of 21 protected nests flooded. Only 12.9% of eggs produced live hatchlings that naturally emerged from the nest. Fourteen percent (15/106) of hatchlings were dead upon excavation, and deaths were attributed to drowning.

Seven productive nests in 1994 contained unhatched eggs; 9 productive nests in 1995 contained unhatched eggs; and 8 productive nests in 1996 contained unhatched eggs (Appendix C). On average, 1.7 unhatched eggs remained in each productive nest in 1994 (22 unhatched eggs; n = 13 productive nests; SD = 2.3); 1.1 unhatched eggs remained in each productive nest in 1995 (16 unhatched eggs; n = 14 productive nests; SD = 1.2); 1.7 unhatched eggs remained in each productive nest in 1996 (19 unhatched eggs; n = 11 productive nests; SD = 0.9). If hatchlings dead upon excavation are included as failed eggs, then, on average, 2.2 eggs failed/productive nest in 1994, 1.4 eggs failed/productive nest in 1995, and 1.8 eggs failed/productive nest in 1996.

In 1996, hatchling mortality approached 100% in nests that were excavated and incubated indoors. Most of these hatchlings were lethargic, had difficulty emerging from the egg, and died within a few days of hatching.

Eggs and hatchlings with developmental abnormalities were recorded in each year of this study. Egg deformities were reported in 1995 and 1996. One egg was approximately 1/2 the size of a normal Blanding's turtle egg; the other was constricted, having a bi - lobed appearance. Both eggs failed, showing no sign of development. In 1994, 7 deformed hatchlings were recorded from 3 of 17 protected nests. In 1995, 7 deformed hatchlings were reported from 7 of 16 protected nests. In 1996, 18 deformed hatchlings were recorded from 7 of 21[10] protected nests. Most developmental abnormalities were atypical shape, arrangement and number of scutes (Appendix E); though these were seemingly benign abnormalities, their effects on survivorship are unknown. More severe developmental abnormalities were also observed, including abnormal gait, partial paralysis, and miniaturization (Appendix E). One hatchling (1996) survived with partial paralysis, a severely deformed carapace, malformed plastron, and a kinked tail (Appendix E).

Predation and mortality

Between June 22 and 25, 1994 female 8-3 lost her left hind leg to an unidentified predator. Although this turtle did not die, she is now incapable of successful nest construction.

Between 1994 and 1996 fewer than 15 Blanding's turtle nests were discovered after predation. Most were predated during the nesting season, although one unscreened nest was found after having been predated between August 29 and September 4, 1995. In the same interval, a protected nest on the Eelweir road was predated, and most protected nests on Glode Island and Atkin' s Beach were disturbed. Although predators were not identified positively, signs of digging around nest boxes were suggestive of raccoons. Flooding, and other unknown factors further reduced nest success in some years (Table 5).

Predation of hatchlings was observed in 1994 and 1995 during the hatchling movement study (Chapter 2). Likely predators include squirrels (McNeil, pers. comm.), raccoons, ants and shrews (Appendix G). In both years numerous trails ended abruptly with no hatchling remains or signs of predator activity. These hatchlings may have been predated by birds.

---

[10] Eggs were not found at one of the 22 sites protected; this 'nest' is not considered here.

Mortality of hatchlings was also observed on Park roads. Newly emerged hatchlings were found dead, often near their roadside nest sites. Most road kills occurred in autumn; however, one turtle was found on May 13, 1996 on the Park's main road near the site of nest 5(95) (Morrison, pers. comm.). Presumably, this hatchling was from nest 5(95) and may have overwintered in a nearby ditch.

Discussion

Review of our current knowledge of the reproductive biology of Blanding's turtles in Nova Scotia (this study, Herman *et al.* 1995, Morrison 1993, 1992, Drysdale 1983, Thexton and Mallet 1979, Dobson 1970, Bleakney 1976, 1963, 1958, Parks Canada, unpublished records).

Prior to the onset of the nesting season, female Blanding's turtles migrate from their aquatic hibernacula to areas near the nesting centres. Though he did not report the minimum temperature at which this activity begins, Power (1989) observed that this migration coincided with rising water temperature. Turtle dispersal begins in late April or early May (Power 1989) and animals arrive at the nesting centres in early June. Although animals were not radiotracked in this study, females were observed migrating toward the mouth of Atkin' s brook in early June (1996); these turtles ultimately nested in the vicinity on either Atkin' s beach or Glode Island. While most females encountered were swimming, females will cross overland, rather than swim around a brook bend (pers. obs.), or trek over longer distances (> 2 km) (Turliuk, pers. comm., Power 1989) to reach nesting areas.

Once near a nesting centre, individuals of three indigenous turtle species (*Chelydra serpentina*, *Chrysemys picta*, and *Emydoidea blandingii*) congregate in shallow coves or bays. Near one inland nesting site turtles congregate in a shallow marsh. Male and sexually immature Blanding's turtles have not been observed in these locations prior to the nesting season. Female turtles leave these coves and bays and return to their home range shortly after nesting (Power 1989).

Shallow, wind sheltered coves and bays appear to be an integral part of 'suitable nesting habitat' for Blanding's turtles. Most females make numerous attempts before successfully completing a nest, and between attempts these sites provide convenient aquatic refugia for gravid females. As well, the warm water (Figures 3a, 3b) and exposed basking sites allow turtles to raise their body temperature which is crucial for the recovery from ionic imbalances and lactate accumulation from overwintering stress (Ultsch *et al.* 1985), and may hasten the final stages of vitellogenesis, increase the efficiency of mobilization of fat reserves and promote (hormonal) readiness for nesting (Hammond *et al.* 1988, Obbard and Brooks 1987, 1978, Ewert 1985, Ganzhorn and Light 1983, Ho *et al.* 1982). Although some females are gravid before arriving at the nesting centres (pers. obs., Power 1989), that only adult female turtles congregate in these areas, and that they vacate these sites after having completed nesting, supports the argument that sheltered coves and bays are a critical feature of suitable nesting areas.

Most nesting occurs in the evening although morning nesting has been infrequently observed (Power 1989). The mean clutch size reported in this study (10.3 eggs) is more accurate and slightly higher than that reported by Power (1989) (Table 5). Clutch size varies within and among individuals (Tables 3a, 3b, 3c), and there is no significant relationship between adult female body size (PL) and maximum clutch size (aCS) (Figure 8 and Power 1989). Females in this population produce a maximum of one clutch per season, and most nest less than annually.

Although the majority (53.6%) of turtles that were observed nesting between 1994 and 1996 nested in mutiple years, and most (60%) of these nested in three consecutive years, many turtles (46.4%) nested only once over the three year period. Assuming that the adult turtle population in the Park has a 1 : 1 sex ratio, and that there are 132 adults (Herman *et al.* 1995), then 13.6% (9/66) of reproductive females nested annually, and approximately 26% (17/66) - 33% (22/66) of the population nests in a given year.

Herman *et al.* (1995) remarked that recruitment into the breeding population appears low in Nova Scotia. That only 2 previously unidentified females were recorded nesting between 1994 and 1996, and that no previously unidentified, mature females were encountered during trapping surveys (McMaster 1996, Morrison, pers. comm.) supports this. Low recruitment[11] may be an artifact of high juvenile mortality and/or a prolonged juvenile stage.

Female Blanding's turtles in Nova Scotia appear to reach sexual maturity around 19 yrs, although McMaster (1996) classified four individuals in this population between ages 17 and 20 as 'juveniles' or sexually immature. While none of these 'juveniles' were found to be gravid nor were observed nesting, they were of similar size to some mature females. However, McMaster failed to sex these 'juveniles' using morphological characters such as plastron concavity, and the possibility that some were males cannot be ignored. Nevertheless, turtles aged 13 years (McMaster 1996) were

---

[11] Only recruitment of females is considered here. The lack of recruitment of females could also be an artifact of incubation temperatures. Since sex in Blanding's turtles is determined by the thermal conditions during incubation, and males are produced at lower temperatures (Packard and Gutzke 1987, Vogt and Bull 1982), more males than females may be produced in this population, which could also account for the low recruitment of females. It would be interesting to know whether the adult sex ratio is biased towards males in this population.

considerably smaller than even the smallest mature female in this study.

Growth ring data from McMaster (1996) and this study suggest that turtles in this population are still growing well into their late teens (Figures 7a, 7b). Were turtles maturing earlier, one would expect to see a plateau in body size around the age of sexual maturation (Congdon and van Loben Sels 1991, Graham and Doyle 1977, Gibbons 1968 b). From these limited data, I can conclude only that Blanding's turtles in Nova Scotia mature after their 13 th year and possibly not until their late teens or early twenties. Since growth ring counts estimate only minimum age, and primiparity cannot be confirmed, my interpretation should be regarded with caution until additional data on individual growth rates become available.

Irrespective of the age at which females reach sexual maturity, Herman *et al.* (1995) suggested that adult females in this population have an extended reproductive lifespan. Using Park records, the reproductive lifespan of two females in this study was estimated. Female 1,0-0 was first observed nesting in 1977, at an estimated age of 20 (Park files). Eighteen years later (1995) she was still reproductive (Table 3c). Assuming the accuracy of the initial age estimate, this turtle was reproductive as she approached age 40. Similarly, female 0-1,0 was first observed nesting on June 18, 1969. Although no age estimate was provided, in 1995 she had been reproductive for at least 26 years. The most conservative estimate assumes that she was in her late teens (17-19) in 1969, and that in 1995 she was approaching age 50. While these data confirm that Blanding's turtles in Nova Scotia have an extended reproductive lifespan it is impossible to assess the possibility of reproductive senescence since most of the reliable records on clutch size and nesting frequency were collected after 1987.

Nesting in this population has been recorded as early as June 8 and as late as July 5 (Table 1). The results of this study confirm previous observations (Morrison 1992 and 1993, Power 1989) that most nesting in Nova Scotia occurs in the last two weeks in June (Tables 1, 2, Figure 1, Appendix B). Because of the intensive and systematic survey schedules in 1994, 1995 and 1996, we can be confident that this trend is real, and not an artifact of differential sampling. There was no evidence in this study to support Power's (1989) suggestion that the nesting season is shorter than elsewhere (Figure 2).

Within the Park, several previously unknown nesting areas were identified during this study. Nevertheless, the results confirm Power's (1989) finding that the natural lakeshore beaches near Atkin's Brook are especially important for Blanding's turtles nesting in the Park. Nesting beaches have good exposure and nests are typically constructed on a slight slope (Figure 4) with a southern or south-western aspect (Figure 5). In Nova Scotia, Blanding's turtles nest in cobble and gravel substrates (Figure 6; Appendix F) within a few meters of open water. Inland nesting occurs occasionally at distances between 200 m and > 1 km from water, and most often along road shoulders. While the distance from nests to water averages 4.46 m (this study), and does not seem to change among years (this study, Power 1989), the proximity of nests to the vegetated beach margin appears to fluctuate annually (Morrison, pers. comm.). This may be partly governed by lake level (Power, pers. comm.). Outside the Park, most nesting reports for this species are along road shoulders and in unpaved parking lots (Morrison, pers. comm.).

The observation that Blanding's turtles in Nova Scotia avoid nesting in sandy areas, especially in fine sand (Power 1989) was, for the most part, supported in this study (Figure 6). However, on two occasions females constructed nests in sand; in one instance the nest wall continually collapsed under the female's weight, and nest construction was successful only with help from the observer; in the second case, the turtle nested in sand during a rain shower when the sand held together. It may be that sandy substrates are avoided because of structural difficulties in nest completion in a similar way that nesting attempts were occasionally aborted because of obstructions (roots or rocks) within the cavity. Although the suitability of a site may be proximately determined by a female's ability to excavate a nest, the range of grain size and sorting of the surface substrate in which Blanding's turtles dig, and successfully nest (Appendix F) suggests that surface substrates are insufficient criteria in determining a site's suitability for nest construction. This is supported by observations of extended periods of searching and sand sniffing as well as the observation that, despite showing high beach fidelity, Blanding's turtles will alternate between, or abandon beaches. This suggests that turtles are able to discriminate between beaches, evaluate sites within beaches and that turtles use a suite of criteria to assess the suitability of nesting sites. Regardless of a site's 'attractiveness' to a female, reproductive success is what ultimately determines a site's suitability for nesting.

Hatching success is low in Nova Scotia even when the effects of flooding and predation are discounted. Most clutches have only partial hatch with an average of 1.4 to 3.2 non-viable eggs per productive clutch (Table 5), and up to 37% of eggs fail to produce viable offspring[12] (1994 and 1995 only, Appendix C). In addition, though incubation times vary among clutches and

---

[12] That is either produce hatchlings that die prior to emergence or fail to hatch (1994 and 1995). It is assumed, in this calculation, that hatchlings excavated alive would have died prior to emergence.

between years (Tables 4, 5 and 6), hatchling emergence in some years may be so late as to result effectively in 100% nest failure (Morrison 1992). While it is unclear why hatching success is low in this population, Herman *et al.* (1995) and Bleakney (1958) suggested that incubation is thermally constrained. Thus, thermal properties of nesting beaches may be critical in determining an area's suitability for nesting, and females may be able to increase reproductive success by selecting sites with optimal thermal characteristics for embryonic development (Shwartzkopf and Brooks 1987). Reproductive success could be improved further by nesting close to sites suitable for neonate overwintering; this would be particularly important in regions where hatching and emergence are late.

Having survived to hatching, neonates enter a new stage of vulnerability. Though it can be difficult or impossible in heavily compacted substrates, such as road shoulders and lakeshore cobble (pers. obs.), or late in the season when cool autumn temperatures restrict activity, emergence generally occurs in September and October after 82 to over 120 days of incubation (Tables 4 and 6). Having escaped from the nest, hatchlings must avoid thermal stress and desiccation, and evade predators; these activities can be complicated by protruding yolk sacs which impede mobility and sometimes tear, and by low temperatures. Furthermore, hatchlings must find suitable overwintering sites. Late emergence and the unpredictable onset of winter in Nova Scotia afford hatchlings little time to locate hibernacula. Though no estimate of hatchling survivorship has been published for this species, it is possible that, because of late emergence in a stochastic environment, hatchlings in this population suffer higher mortality than elsewhere, making their protection all the more important to the survival of this threatened population. Studying hatchling behaviour will provide insight into the habitat requirements of young turtles, and will improve our ability to protect them. Neonatal behaviour is investigated in Chapter 2.

CHAPTER 2.

Post-emergence behaviour of neonate Blanding's turtles, *Emydoidea blandingii*, in Nova Scotia.

Though Blanding's turtles have been characterized as having a Type III survivorship curve in which mortality rates are inversely related to age (Iverson 1991), and populations should thus be tolerant of high mortality in young age classes, low recruitment, and the skewed age structure in the Blanding's turtle population in Nova Scotia (Herman *et al.* 1995) have necessitated management practices that improve survivorship of young age classes. For logistical and practical reasons (such as the apparent lack of sexually immature turtles), wildlife managers at Kejimkujik National Park initiated a nest protection programme. Given the limited survivorship of Blanding's turtle eggs and low hatchling emergence success in Nova Scotia (Chapter 1), offsetting the effects of predation by protectively screening nests can only be beneficial. But this is insufficient. To bolster recruitment into the adult, breeding population, protecting young turtles (Heppell 1996, Iverson 1991) and their habitat is imperative; to accomplish this, a greater understanding of the early life history of Blanding's turtles is required.

For many freshwater turtle species, information on the early life history of Blanding's turtles is mostly limited to reports of clutch size and survivorship, and hatching success (Herman *et al.* 1995, Power 1989, MacCulloch and Weller 1988, DePari *et al.* 1987, Petokas 1986, Congdon *et al.* 1983, Bleakney 1963, Brown 1927, Snyder 1921). Few studies have investigated the behaviour and habitat requirements of sexually immature individuals (McMaster 1996, Pappas and Brecke 1992), and virtually nothing is known about hatchlings of this species (McNeil 1996, Butler and Graham 1995).

To date, the most significant contributions to our understanding of the behaviour and habitat requirements of neonate Blanding's turtles have been provided by Butler and Graham (1995). These authors concluded that newly emerged hatchlings in Massachusetts move from their inland nests to wetlands, likely in search of aquatic hibernacula. However, some of their results appear at variance with this conclusion, primarily because of ambiguous terminology, and the location of their study site (inland) which did not facilitate the investigation of the orientation mechanism. The small sample size further limits the interpretive value of the study at the population level, and at the species level.

While there are many similarities between the Nova Scotia population and those elsewhere, behavioural divergence has been identified in adults in this disjunct population (Herman *et al.* 1995, Power *et al.* 1994, Power 1989). It is suspected that divergent behaviours are responses to environmental constraints at the northeastern limit of the species' range (Chapter 1, Herman *et al.* submitted). Since the protection of sexually immature turtles is a crucial component of the successful recovery of Nova Scotia's Blanding's turtle population (Herman *et al.* submitted, Iverson 1990) the possibility of behavioural divergence in young age classes must not be overlooked in the development of management strategies.

It is generally assumed that freshwater turtles go to water upon emergence from the nest (Ehrenfeld 1979). However, because of the limitations of Butler and Graham's (1995) study, the possibility of behavioural differences in neonate turtles at the edge of the species' range, as well as anecdotal evidence from the Nova Scotia population that contradicted this assumption (Morrison pers. comm.), an intensive investigation of the early post-emergence behaviour of hatchlings in this population was initiated.

The unique nesting habits of *E. blandingii* in Nova Scotia provide ideal circumstances for investigating neonate behaviour. Elsewhere in the species' range, including Massachusetts (Butler and Graham 1995), Blanding's turtles typically nest inland and away from open water (Butler and Graham 1995; Ross and Anderson 1990; Petokas 1986; Congdon *et al.* 1983); the Nova Scotia population differs in that females tend to nest on cobble lakeshores (Chapter 1). Though some females in this population nest inland at distances over 100 m from open water, the majority nest within 5 m of open water. Consequently, despite fluctuations in lake level, emergent hatchlings have an unobstructed view of water. In the current study the water seeking strategies of hatchling Blanding's turtles are more closely examined than was possible in the previous study by Butler and Graham (1995). The duration of this investigation (2 seasons) also allowed for a larger sample. Thus, statistical analyses as well as qualitative descriptions of hatchling behaviour are provided.

It is intended that this study complement the work of Butler and Graham (1995), providing further insight into the adaptations of *E. blandingii* as a species, and the particular adaptations of young turtles in this disjunct population. The hypothesis is that hatchling Blanding's turtles go to water immediately upon emergence from the nest.

Materials and methods

Study site

This study was conducted in Kejimkujik National Park, Nova Scotia

(44° 15′- 44° 30′ N, 65° 00′- 65° 30′ W) (Figure 1) during summer and autumn 1994 and 1995. Nesting and hatchling movement data were collected at the major nesting centres, including four beaches and one inland site (Power 1989). As well, in 1995, one nest was sampled on a newly discovered nesting beach.

Nesting beaches have a gradual slope and typically comprise fist-sized cobble and large pebbles. Beaches are sparsely vegetated with grasses, rushes, and cranberry (*Vaccinium macrocarpon*) (Roland 1945). The upper beaches are bordered with huckleberry (*Gaylussacia baccata*), blueberry (*Vaccinium* spp), leatherleaf (*Chamaedaphne catyculata*), sweet gale (*Myrica gale*), red and white pine (*Pinus resinosa, P. strobus*), and maple (*Acer* spp).

Inland nests were constructed in the gravel shoulder on the North side of a two-lane, paved road. The shoulder is 2 m wide on either side of the road, and descends into a more steeply sloped bank of mowed vegetation. The lower-banks are bordered by a steep forested incline (predominantly *Pinus strobus*). A dense mat of moist *Sphagnum* spp (0.5 - 1.0 m wide) occurs along the base of the South side slope. The nearest open water is a small marsh located North of the road, between 100 - 150 m West of the sampled nest sites.

Nesting and emergence

Beaches and roadsides were surveyed for nesting *E. blandingii* throughout June, 1994 and 1995. Nests were protected against predation with a raised, wire-mesh cage once nest construction was complete; this cage also served as a pen for emergent hatchlings. Beginning September 1 in both years, nests were checked regularly for emergent hatchlings. In late October all nest cavities were excavated to determine the number of unhatched eggs and to free any remaining hatchlings. Upon discovery hatchlings were measured (maximum carapace length, CL), notched for identification (Standing *et al.* 1995), dusted with tracking pigment, and released.

Dusting and tracking

Coloured powder, which fluoresces under UV light (Radiant Color, LBRS Series, Richmond, CA), was used to track emergent hatchlings (Butler and Graham 1993). Hatchlings were dusted using a cotton swab, covering the carapace, plastron and leg sockets, but especially avoiding contact with the eyes and nostrils (Stapp *et al.* 1994). Nestmates were assigned different colours whenever possible so individual trails could be distinguished during tracking. Hatchlings were released at the nest site in random orientation and were left undisturbed.

At night, powder trails were followed using hand-held UV lamps (Raytech Raytector ®), and marked with flagging tape secured with pebbles. Flagging tape was superimposed on the entire length of most trails, though in some cases, it was laid at intervals. If a hatchling was found at the end of a trail its location was marked and it was re - dusted with the original pigment. To minimize disturbance on such occasions, the area immediately surrounding the turtle, rather than the turtle itself, was powdered; hatchlings walked through the powder as they resumed their trek, thereby facilitating the collection of data over several days.

Flagged trails were mapped using a compass (azimuth to the nearest degree; magnetic North), and a measuring tape or meter stick (to the nearest 0.1 cm). Trails were mapped in relation to water, vegetation, topography, the nest of origin and other trails (Figures 9a - 9g).

Trail analyses

Trail data were analyzed using circular statistics (Batschelet 1981, 1965;

Zar 1984). Most studies of the post-emergence movement of hatchling turtles have employed the Rayleigh's test. However, in this study, the *V* test is used. The two analyses are similar in that each tests whether a set of angles differs significantly from randomness. However, in addition to being more powerful in rejecting randomness when animals are not clearly directed (Batschelet 1981), the *V* test is more appropriate for testing whether observed angles cluster around a hypothetical direction (θ_o); in this case, the hypothetical direction, selected *a priori*, is in the direction of the nearest water. The null hypothesis is that the parent population, from which the sample ($\psi_1, \psi_2, \ldots, \psi_n$) is drawn, is randomly (uniformly) distributed about the hypothetical direction (θ_o).

The orientation from nest to nearest water was standardized among nests, within years such that the orientation (ψ) of the resultant vector (R) of each hatchling's first day trek was converted to the polar angle ψ' (Batschelet 1965). By letting $\psi_1, \psi_2, \ldots, \psi_n$ be n observations of hatchling orientation (azimuth clockwise from North) on day 1 from a single nest, and letting β be the direction to nearest water from this nest, the original zero direction (North) is rotated so that β becomes the new zero direction θ_o. This yields the new polar angle ψ' from the original ψ. The new polar angle is defined by:

$$\psi' = \psi - \beta$$

The value is either positive or negative corresponding to either a clockwise or counter clockwise rotation from θ_o.

The new sample ($\psi'_1, \psi'_2 \dots \psi'_n$) for each year was then plotted on a unit circle, and the mean vector (m'), its length (r') and its polar angle (ϕ') were calculated. The component of the mean vector with respect to the direction to nearest water, or 'the homeward component' (v), and the test statistic (u) were then calculated (Batschelet 1981). If the critical value $u(\alpha)$ was less than or equal to the test statistic (u), the null hypothesis of randomness was rejected.

To investigate the possibility that hatchlings were organized with respect to some feature other than water, a phenomenon that would be masked by the *V* test, nests were examined independently for patterns in first-day movement among nestmates. By plotting the original ψ samples separately for each nest and calculating the mean vector (m) and its length (r), the length of the mean vector is used as an index of angular dispersion among nestmates (Zar 1984). Since the sample size (n) within nests is small, I arbitrarily defined nests with $r > 0.6$ as 'directed'. If the polar angle (ω) of the mean vector was in the direction of nearest water (β) such that:

$$|\beta - \omega| < 25^{\circ}$$

and $r > 0.6$, then hatchling movement on the first day after emergence within the nest was considered to have been 'directed toward nearest water'.

To assess the straightness of an individual's course among days the resultant vector (R'') and corresponding angle (ψ'') of each day's trek was plotted. If the range (λ), the smallest arc containing all data in the distribution, was less than or equal to 22.5° (an arbitrarily chosen limit) the turtle was considered to have followed a consistent bearing among days. Since several turtles were stationary between days the first and second day of travel do not necessarily correspond to the first and second day after release.

Results

Nesting and emergence

Fresh Blanding's turtle nests were protected between June 15 and June 25, 1994, and between June 16 and June 29, 1995. Emergence began September 6, 1994 and September 13, 1995. Mean incubation time (days from oviposition to emergence) was 94.8 days in 1994 and 90.1 days in 1995. Hatchlings continued to emerge naturally from the nest until mid-October in both years. The latest recorded natural emergence for this population (excluding live hatchlings at excavation) occurred on October 25, 1995. Emergence within nests was mostly asynchronous in both years, lasting between 2 and 10 days in 1994, and between 2 and 11 days in 1995. Live hatchlings were uncovered during nest excavations in October of both years.

In both years 93.3% of successfully protected nests were productive, that is, produced at least one live hatchling. Of 103 hatchlings observed in 1994, 80.6% naturally emerged from the nest (*i.e.* emerged unaided), 12.6% were alive when excavated, and 6.8% had successfully hatched but had died before emerging from the nest. In 1995, of all hatchlings observed (n = 119) 83.2% naturally emerged, 14.3% were alive when excavated, and 2.5% were dead upon excavation. Hatchling body size was not significantly different between years (1994 mean CL = 33.1 mm; n = 88; SD = 1.6; and 1995 mean CL = 33.5 mm; n = 100; SD = 1.9; $t_{0.05,(2),186} > 0.0587$, $\alpha = 0.05$).

Of the six beach nests sampled for hatchling movement in 1994, one faced Northeast (azimuth: 84°), one due South, and four had a Southwest aspect (azimuth: 230°, 240°, 230°, 225°); the mean distance between beach nests and the vegetated beach edge was 2.71 m (n = 6; SD = 1.87; range: 1.0 m - 4.94 m) and at emergence the mean distance between nests and the nearest water was 9.43 m (n = 6; SD = 4.48; range: 4.8 m - 15.2 m). Of the six beach-nests sampled in 1995, three faced Southeast (azimuth: 101°, 187°, 172°), and three faced Southwest (azimuth: 222°, 228°, 276°); the mean distance between beach nests and the forest edge was 2.88 m (n = 6; SD = 1.47; range: 1.7 m - 5.57 m), and at emergence the mean distance between beach nests and the nearest water was 16.5 m (n = 6; SD = 9.37; range: 11.0 m - 34.95 m). The one roadside nest sampled in each year was approximately 7 m from the forested incline, and between 100 m to 150 m from the nearest water.

In 1994, forty-two turtles, from 7 nests, were trailed for a maximum of 4 days. One of these was not powdered. In 1995, thirty-six hatchlings from 7 nests were powdered in 1995 and tracked for a maximum of 11 days.

In both 1994 and 1995 hatchling orientation on the first day after emergence from the nest was random with respect to nearest water ($\alpha = 0.05$) (Figures 10a,10b). Nestmates from 3 nests sampled in 1994 displayed directed movement on the first day, but only one of these showed movement directed toward nearest water (Table 6); it is noteworthy that neither hatchling from this nest actually entered water (Figure 9a).

Results in 1995 were similar. Four nests showed no directed movement among nestmates on the first day of travel, and a single hatchling from a fifth nest did not move in the direction of nearest water (Table 6). Although nestmates from two nests displayed directed movement toward water, most hatchlings did not actually enter it on the first day.

Of 27 turtles for which multi-day data are available, 6 followed a consistent bearing between the first and second day of travel (Table 7). Of 9 hatchlings for which more than 2 days of travel data are available, only one was consistent among days (4 days; $\lambda = 5.8$). This hatchling, maintained a route almost parallel to the water line; ultimately its trail was lost at the forest edge (Figure 9d).

Trail description

While the interpretation of trends within and among clutches is important, inspection of individual trails revealed some of the most curious results.

First, most hatchlings did not maintain a straight course among days (Table 7). Even within days, hatchlings frequently changed direction, frequently backtracking as well as crisscrossing their own trail. Convoluted trails were restricted to areas with little or no vegetation cover. Interestingly, all hatchlings, regardless of the character of their trail in the open, navigated along straight courses while under vegetation cover.

Second, numerous hatchlings in this study avoided water (Figures 9c and 9d). On several occasions hatchlings followed straight trails in the direction of water, but veered either after having reached it, or within a few meters of the shoreline (Figures 9a, 9c and 9d). In 1994, six of 42 trails ended in water or < 10 cm from the water's edge; it is expected that these turtles entered water. Two hatchlings whose trails were lost > 2 m from water were observed at the shoreline aquatic-basking three days after their initial release. One hatchling that entered water, re - emerged approximately 6 m West of the point of entry and proceeded up the beach (Figure 9f). Of 36 turtles tracked in 1995, 8 trails ended in water; of these, 1 entered water on the first day of travel, walked less than 10 m along the shoreline, and emerged to spend its first night on shore (Figure 9g).

Third, hatchlings were observed using overnight and daytime forms (sleeping and resting sites) similar to those described by Butler and Graham (1995), buried in leaf litter, sphagnum or other vegetation, or nestled between beach cobble and under roots and logs. Hatchlings also used aquatic overnight forms. In 1995, two hatchlings were observed in aquatic, overnight forms in < 3 cm of water. In 1995, several hatchlings spent the night exposed on the beach when temperatures fell below freezing (- 5.5^{o} C). Fossorial movements were observed in 1994 and 1995. These individuals proceeded from a terrestrial form along a route approximately 10 cm beneath sphagnum and leaf litter.

Generally, hatchlings showed no propensity for seeking cover, nor for following slope. Infrequently, trails overlapped, but only for short distances. Nestmates released on the same day showed no tendency to move in the same direction as one another on the day of release or on subsequent days.

Discussion

Many selective advantages for post-emergence water-seeking behaviour in hatchling turtles are presumed, although few supporting data are available. Advantages include the avoidance of avian and terrestrial predators, access to suitable basking and feeding habitat, and decreased risk of thermal stress and desiccation. Water is thought to be particularly important for freshwater turtles at high latitutes whose hatchlings emerge from the nest in autumn because it provides insulation against tissue freezing during winter.

Throughout their range Blanding's turtle hatchlings emerge from the nest in autumn (Butler and Graham 1995, Ernst and Barbour 1989, Power 1989, Congdon *et al.* 1983, Bleakney 1963) and it is generally assumed that neonates seek aquatic hibernacula (Butler and Graham 1995, Ehrenfeld 1979). However, females typically nest inland (Butler and Graham 1995, Ross and Anderson 1990, Petokas 1986, Congdon *et al.* 1983) where the view of water from the nest site is often obscured by vegetation. Although few detailed descriptions of nesting sites exist for this species (Butler and Graham 1995, Power 1989, Petokas 1986), it appears that the nearest water to inland nests is often marsh or wetland, and not a large body of open water (Butler and Graham 1995, Power 1989, Petokas 1986, Congdon *et al* 1983). It is unlikely then, that orientation mechanisms similar to those of neonate marine turtles and beach-nesting freshwater turtles have evolved in Blanding's turtles. That is, it is unreasonable to assume that *E. blandingii* hatchlings use cues such as slope, photic gradients, open horizon, and vegetation silhouette (Lohmann and Lohmann 1996, Godfrey and Barreto 1995, Salmon *et al.* 1992, Witherington and Bjorndal 1991, Ehrenfeld 1968, Ehrenfeld and Carr 1967, Anderson 1958) upon emergence since these cues would be ineffective in orienting from inland nests.

These findings support those of Butler and Graham (1995) who concluded that slope, open horizon and the silhouette of nearby vegetation do not appear to be critical cues in the orientation of hatchling *E. blandingii*. Although Butler and Graham (1995) provided limited evidence to support an olfactory component in orientation, that simultaneously released nestmates tended to disperse randomly in this study (Figures 9b, 9c and Table 7) implies that hatchlings do not fixate on an olfactory cue any more than on any structural feature. This, however, does not preclude the possibility that the orientation mechanism has an olfactory component.

Although these data suggest that hatchlings neither seek nor avoid vegetation cover, individual trails were often convoluted in the open, and relatively straight while under vegetation. This pattern was also noted by Butler (pers. comm.) suggesting that, while the orientation mechanism is not totally impaired in the open, vegetation cover may improve its effectiveness. The possibility that vegetation structure influences the efficiency of movement in hatchling Blanding's turtles warrants further investigation.

Regardless of the cues and orientation mechanism, natural selection should favor mechanisms allowing animals to organize their movement with respect to their environment so as to avoid random wandering (Able 1991). If water-seeking behaviour is adaptive, newly emerged neonate Blanding's turtles should be able to find water with relative efficiency. Thus, if neonates 'seek' water, their movements should be organized in such a way that they reach their goal as directly as possible.

Although these results support Butler and Graham (1995) in the lack of orientation toward open horizon, they fail to support their conclusion that hatchlings 'seek standing water' upon emergence from the nest. In fact, some of the results in their own report do not agree with this conclusion. For instance, although hatchlings 'repeatedly and non-randomly sought [wetland habitat] in the absence of standing water', the majority of hatchlings tracked in their study 'necessarily deviated from a straight course for water' in order to encounter vernal pool habitat, and disproportionately used dry vernal pool habitat (Butler and Graham 1995).

Hatchlings moved randomly with respect to nearest water (Figures 10a and 10b), and while several turtles entered water, others overtly avoided it (Figures 9c, 9d). Data from McNeil (1996) suggests that hatchlings released at the shoreline are repelled by water. These results imply that water is not the goal, and that no simple habitat feature is sought. The behavioural variation of emergent hatchlings, as well as the tendency of nestmates to disperse in both the Nova Scotia and Massachusetts populations, suggests that hatchlings of this species have a bet-hedging or adaptive coin-flipping strategy upon emergence (Cooper and Kaplan 1982, Cooper 1981). In an unpredictable environment such as Nova Scotia, where the onset and severity of winter varies among years, and hatchling emergence is delayed until mid-September and October, a mixed-strategy would ensure that some offspring survive.

Congdon *et al.* (1983) provide anecdotal evidence of Blanding's turtle hatchlings overwintering in the nest. While this has not been substantiated in the literature, delayed emergence may be a facet of a mixed strategy (Ewert 1985, Gibbons and Nelson 1978). Although Power (1989) reported that hatchlings excavated in November appeared dormant, hatchlings excavated during this study were often active, and were likely capable of successful emergence. However, even if Blanding's turtle hatchlings are physiologically capable of withstanding terrestrial hibernation, it is unlikely that this could be accomplished in the nest cavity in Nova Scotia, at least in lakeshore nests, since ice scouring and spring flooding often destroy overwintering nests (Morrison pers. comm.). Nevertheless, terrestrial hibernation remains a possibility, in both this population and in those elsewhere.

In order for hatchlings to overwinter successfully on land they would have to: 1) withstand tissue freezing (*i.e.* being freeze tolerant); or 2) avoid tissue freezing, either behaviourally (*e.g.* by burrowing below frost line), or physiologically (*e.g.* supercooling) (Packard and Packard 1995, 1990, Claussen *et al.* 1991, Storey *et al.* 1988). The capacity to withstand tissue freezing may only be advantageous for short-term freezing at high sub-zero temperature (Packard and Packard 1995), and while Packard (pers. comm.) has recently completed work confirming that Blanding's turtles from Nebraska are able to withstand short-term tissue freezing, avoiding freezing altogether is likely more advantageous to overwintering success. Nonetheless, numerous hatchlings in this and McNeil's (1996) studies survived overnight at temperatures below freezing (- 5.5ºC). This suggests that hatchlings Blanding's turtles in the Nova Scotia population also have the capacity to withstand freezing, or at least, to supercool (Packard, pers. comm.). This observation, coupled with the water avoidance and fossorial movements of some hatchlings, and the observation of terrestrial hibernation of adults (Rowe and Moll 1991), suggest that terrestrial hibernation is possible for hatchling Blanding's turtles in Nova Scotia. Terrestrial hibernation may explain why, in May 1996, a hatchling Blanding's turtle was found along a road near the site of what was likely its natal, inland nest. Although it is possible that this hatchling spent the winter in a marsh aprroximately 250 m distant, or in an inundated ditch, it is equally plausible that it used a terrestrial hibernaculum.

The Nova Scotia Blanding's turtle population presents interesting management challenges, in part because of its small size and patchy distribution, and in part because of its behavioural divergence from populations elsewhere (Herman *et al.* 1995, Power *et al.* 1994; Power 1989). While it remains unresolved whether neonatal behaviour differs between the Nova Scotia and Massachusetts populations, there are substantive conclusions about the importance of the terrestrial habitat surrounding nesting areas. From inland nests, hatchlings in search of aquatic hibernacula must traverse intervening terrestrial habitat. Even the most direct routes to water can be over 50 km, and overland treks can take several days (Butler and Graham 1995). As well, neonates may use terrestrial hibernacula in the vicinity of nesting beaches (this study). The availability of vegetation cover and other features (*e.g.* moist moss beds) could be important for predator avoidance and thermoregulation (Butler and Graham 1995), and the efficiency of the search for hibernacula may be influenced by the vegetation structure (this study). Further, if hatchling Blanding's turtles use terrestrial hibernacula the existence and distribution of critical habitat could severely affect overwintering success. For the survival of hatchling Blanding's turtles, the maintenance of terrestrial habitat adjacent nesting areas could prove as important as the protection of nest sites. The need for such habitat protection is made all the more poignant by the apparent scarcity of young turtles in the Nova Scotia population (Herman *et al.* 1995).

Since sexual maturation is late in Blanding's turtles as compared with other turtle species (Congdon *et al.* 1993) the likelihood of reaching reproductive age is low (Heppell *et al.* 1996, Congdon *et al.* 1993). If the Nova Scotia population is thermally constrained (Bleakney 1958), growth and maturation of young turtles may be compromised (Avery *et al.* 1993, Congdon and van Loben Sels 1991) and the rate of recruitment may be low relative to other populations of this species (Heppel *et al.* 1996). If, as suggested by Power (1989) and Herman *et al.* (1995), reproduction is also constrained, this population may be more sensitive to habitat modification or other disturbances effecting increases in mortality, particulaly in young age classes (Congdon *et al* 1993, Iverson 1991). In the following chapter these suggestions (Herman *et al.* 1995, Power 1989, Bleakney 1958) are investigated in relation to nest site selection and the habitat requirements of Blanding's turtles in Nova Scotia.

Chapter 3.

Temperature: the primary factor constraining reproduction and limiting the distribution of Blanding's turtles (*Emydoidea blandingii*) in Nova Scotia.

Since its first discovery in 1953 (Bleakney 1958) the Blanding's turtle population of Nova Scotia has been considered enigmatic because of its isolation from the main range (Figure 1, Bleakney 1958), its behavioural divergence from other populations (Herman *et al.* 1995, McMaster 1996, McNeil 1996, Power 1989), and its restricted range within the province (Herman *et al.* 1995, Bleakney 1958). Although there is some dispute over the means by which the species became established and subsequently isolated in Nova Scotia (Herman *et al.* 1995, Bleakney 1958), what is of immediate concern to the recovery of this threatened population is the identification of factors limiting its current distribution. Identifying critical habitat features will improve our ability to locate areas of concentration (Power *et al.* 1994), and possibly to enhance and restore Blanding's turtle habitat in Nova Scotia (Herman *et al.* submitted). As well, a better understanding of the ecology of this population is essential for its protection and management.

Throughout their range Blanding's turtles use a variety of aquatic habitats though they predominantly occupy shallow still waters (bogs, marshes and lakes) characterized by deep organic sediments, and submergent and emergent vegetation (Herman *et al.* 1995). In Nova Scotia, Blanding's turtles of all ages occur in slow-flowing brooks and streams (pers. obs., McMaster 1996, Power 1989) and the population's distribution is tightly positively correlated with dark waters (Power *et al.* 1994), and especially with peaty soils (Power *et al.* 1989) and floating mats of *Sphagnum* (McMaster 1996, Power 1989). While the cause of these correlations has not been formally determined, Power *et al.* (1994) proposed that the association between Blanding's turtles and their habitat is food-related. Indeed, their distribution within Kejimkujik National Park parallels that of areas with high secondary productivity (Power *et al.* 1994), and it stands to reason that primarily carnivorous Blanding's turtles (Herman *et al.* submitted) should concentrate in areas of high food abundance, particularly in relatively oligotrophic systems (Herman *et al.* 1995, Power *et al.* 1994, Power 1989). However, habitat productivity does not satisfactorily explain the population's severely restricted range within the province, since both snapping turtles (*Chelydra serpentina*) and painted turtles (*Chrysemys picta*) have similar diets as Blanding's turtles (Congdon 1989), yet they are more widespread (Cook 1984).

Of the four turtle species occurring in Nova Scotia, snapping turtles (*Chelydra serpentina*), painted turtles (*Chrysemys picta*), wood turtles (*Clemmys insculpta*), and Blanding's turtles (*Emydoidea blandingii*), only the latter species is restricted to the southwestern interior (Figure 1) (Herman *et al.* 1995, Cook 1984, Bleakney 1958). The obvious question is, why?

It has been suggested that the limited distribution of Blanding's turtles, particularly at the northern boundary of the species' range, reflects thermal constraints (Herman *et al.* 1995, Power 1989, Gutzke and Packard 1987, Bleakney 1958). The latitudinally compressed species' range (Figure 1), and its apparent shift in response to climatic changes following the last glaciation (Herman *et al.* 1995), suggest that Blanding's turtles are particularly sensitive to temperature (Herman *et al.* 1995). Indeed, they are relatively intolerant of high temperatures (Hutchison *et al.* 1966), but perhaps more important at the northern limit of the range, their eggs have a high critical thermal minimum (Gutzke and Packard 1987). Not only would low temperatures during incubation lengthen the interval between oviposition and hatching, but poor thermal conditions could reduce hatching success (Gutzke and Packard 1987), thereby limiting the distribution of the species. Bobyn and Brooks (1994) advanced a similar argument for snapping turtles (*Chelydra serpentina*), and the suggestion that incubation conditions limit the northern distribution of turtles is not new (Bleakney 1958, Allard 1935).

The Nova Scotia population is restricted to the southwestern interior, the warmest region in the province (Herman *et al.* 1995). This congruency suggests that, at least in Nova Scotia, the distribution of the species reflects thermal constraints on incubation. Power (1989) and Herman *et al.* (1995) intimated this and were the first to provide supporting data. Although these data were insufficient to generalize about the population, Herman *et al.* (submitted) implicitly assumed the accuracy of the interpretation when advancing the postulate that behavioural divergence of nesting females is an adaptive response mitigating the thermal constraints on incubation. But it remained to be tested whether nest site selection was related to thermal properties of the environment.

In this chapter, I satisfy the second and third objectives of this thesis. In addition to defending the claims that in Nova Scotia Blanding's turtle reproduction is compromised by 'climate', *i.e.* thermal conditions (Herman *et al.* 1995, Power 1989), and that temperature is the primary factor limiting distribution, I present results of an experiment examining the thermal properties of nest sites.

Methods

This population is small and each year nests are diffuse throughout the park; often a single nesting beach supports fewer than a dozen Blanding's turtle nests in a season. It is a challenge to distinguish between sites that are avoided because of their thermal unsuitability, and those that are not used as an artifact of small population size.

Historical records revealed that Blanding's turtles naturally subdivided the three major nesting beaches, Glode Island, Atkin' s Beach (I) and Heber Meadow Beach (II), into nesting and non-nesting sections (Morrison 1993, 1992, Herman unpublished records, Power 1989). That is, Blanding's turtles consistently and predictably restrict nesting activities to particular sections within each beach. To determine whether the subdivision of individual beaches might be related to the thermal microclimate I compared the thermal characteristics of nest sites and randomly selected sites within the non-nesting section.

Nests constructed on the main nesting sections of Glode Island, Heber Meadow Beach (II) and Atkin' s Beach (I) were screened against predation on the night of oviposition (Chapter 1). The location of each nest was measured in relation to water and the vegetated edge of the upper beach. Each nest was paired with a 'dummy' site selected randomly along the length of the non-nesting section of the same beach (as determined from historical records). Dummy nests had the same relative position along the beach width as their nest pair, such that pairs were located on the same contour line.

Automated temperature loggers (Hobo ®) were installed at average nest depth (ca. 12 cm, Power 1989) at nests and 'dummy' nests. To minimize the disturbance of eggs, and to exclude their possible influence on temperature (Brodie *et al.* 1996, Packard and Packard 1988), thermistors at nest sites were buried approximately 10 cm outside the nest cavity. Nests and dummy nests were screened and thermistors were centered as much as possible within the screened frames. Temperature was recorded at regular intervals (ca. every 0.5 hour) throughout the incubation period (Table 8). Between 1995 and 1996, fourteen nest - dummy nest pairs were sampled on the three main nesting beaches.

Calculation of cumulative heat units:

The minimum threshold for development of Blanding's turtle embryos was first estimated by plotting developmental rates against temperature (data from Ewert (1979) and Gutzke and Packard (1987)). Assuming that the embryo's response to temperature is linear (Baskerville and Emin 1969) the minimum threshold for development is estimated by the intersection of the regression line and the x-axis (Figure 11a). For any time interval, the number of heat units accumulated approximates the area under the temperature curve that lies above the minimum threshold (Baskerville and Emin 1969). In this study one heat unit is defined by:

$$(Ti_m\,(^\circ C) - T_t\,(^\circ C)) \times I$$

Where Ti_m ($^\circ$ C) is temperature measured at instant i, T_t ($^\circ$C) is the minimum threshold temperature for development (14°C) (Figure 11a), and I is the interval (days) between consecutive temperature recordings (Table 8). The primary assumptions are that the organism's response to temperature is linear (Baskerville and Emin 1969), and that the tolerance to the minimum temperature threshold is constant throughout development. Neither assumption is biologically accurate (Deeming and Ferguson 1991, Packard and

Packard 1988, Ewert 1985) and the calculated minimum threshold temperature should not be interpreted as having any biological relevance. Regardless, calculating cumulative heat units is a method of quantifying the thermal properties of a site, in this case the nests and dummy nests, so that they can be compared with relative simplicity (Figure 11b). For cumulative heat unit calculations to be comparable within pairs, recordings must be collected at the same frequency (mins.) during the same interval. Because of equipment failure, only sub-sets of the data were compatible and suitable for analysis (Table 8). The difference between the cumulative heat units of the nest - non-nest was calculated for each pair, and a one-tailed *t* test was performed on these values to test the hypothesis that nest sites were warmer than their non-nest pairs (*i.e.* H_0: $\mu \leq 0$).

Results and Discussion

Reproductive potential can be defined at the individual and population levels. It is a measure of the number of offspring produced over time. It incorporates intra- and inter-annual clutch frequency and offspring number, which in the case of oviparous organisms is analogous to clutch size, *i.e.* egg number. For long - lived, iteroparous species, clutch frequency is considered the most important population characteristic (Gibbons and Greene 1990, Gibbons 1968 a).

There are no published reports of Blanding's turtles producing more than a single clutch per year, and few data of inter-annual clutch frequency exist making comparisons difficult. Based on the population estimate for Kejimkujik National Park (Herman *et al.* 1995) the highest proportion of adult females reproducing in a single year during this study was 33% (Table 9). Though some females reproduced annually, at least over the three year period 1994 - 1996 (Table 3a), most nested less frequently (Tables 3b, 3c). These observations are consistent with earlier data from this population (Herman *et al.* 1995, Morrison 1993, 1992) and with reports from Michigan (Congdon *et al.* 1983) (Table 9) and Ontario (Petokas 1986). Thus, Blanding's turtles in Nova Scotia are similar to those elsewhere in that many nest less than annually. Clutch frequency may be lower in Nova Scotia relative to other populations, but this possibility cannot be evaluated from these limited data. Nevertheless, the examination of other aspects of reproductive potential, such as annual reproductive potential (clutch size), and the reproductive lifespan suggests that reproduction in Nova Scotia is constrained.

Whereas clutch frequency is thought to be influenced primarily by extrinsic factors such as resource availability, clutch size is thought to be constrained morphologically (Gibbons and Greene 1990). This is because in many turtle species, and in some Blanding's turtle populations (Congdon and van Loben Sels 1991, MacCulloch and Weller 1988, Petokas 1986) there is a significant positive correlation between female body size and clutch size. While adult female Blanding's turtles in Nova Scotia are of similar size to those in other populations (Herman *et al.* 1995, Power 1989, this study) the relationship between body size and clutch size is not statistically significant (Figure 8, Appendix A, Power 1989). Turtles in Nova Scotia may be incapable of realizing their maximum annual reproductive potential (*i.e.* clutch size), not because of morphological constraints, but because of extrinsic factors such as the availability and quality of food and other resources (Gibbons and Greene 1990, Congdon 1989).

Power *et al* . (1994) observed that local concentrations of Blanding's turtles in Nova Scotia paralleled areas characterized by high secondary productivity. Though these sites are productive relative to habitat in the immediate area, Blanding's turtles in Nova Scotia occupy oligotrophic waterways (Herman *et al.* 1995, Power *et al.* 1994, Power 1989). An analysis of productivity and diet between populations could reveal differences in habitat quality between Nova Scotia and elsewhere. Differences in habitat quality could explain, at least in part, differences in reproductive characteristics (*e.g.* clutch size and nesting frequency) between populations. Alternatively, the Nova Scotia population may not be constrained by the abundance and quality of food, but by a shorter and cooler active season.

While the length of the active season affects the amount of time available for turtles to harvest food, it is the thermal environment which influences appetite, ingestion and processing rates, digestive efficiency, reproductive cycles, egg quality, clutch size, clutch frequency, sexual maturation, and growth rates of turtles (Avery *et al.* 1993, Noble 1991, Congdon 1989, Hammond *et al.* 1988, Obbard and Brooks 1987, Ewert 1985, Ganzhorn and Light 1983, Ho *et al.* 1982, Thornhill 1982, Parmenter 1980). By limiting the amount of food accumulated and processed over a summer, and hence the reserves available for reproduction, low summer temperatures could constrain annual reproductive potential. As well, sub-optimal temperatures would reduce growth rates of young turtles, and this could compromise lifetime reproductive potential, particularly if sexual maturation is a function of juvenile growth rate (Congdon and van Loben Sels 1993).

Although hatchlings are of similar size in Nova Scotia as elsewhere, juvenile growth in the Nova Scotia population appears slower than reports from Michigan (Figures 7a and 7b, McMaster 1996, Congdon and van Loben Sels 1991). Congdon and van Loben Sels (1991) reported that weight increased

75.3 g annually between ages 4 and 13 years and juveniles grew an average of 1.04 cm (CL) per year from 1 to 13 years. In contrast, juvenile Blanding's turtles in Nova Scotia on average gained 54.94 g per year (Figure 7a) and grew 0.82 cm (CL) per year (Figure 7b). By age 18 Michigan turtles reached a plateau of 1200 g which is 230 g to 431.5 g heavier than similar aged individuals in Nova Scotia (McMaster 1996). Although some individuals in Michigan continued to grow (ca. 1.0 mm/ year) after reaching sexual maturity, sexual maturation coincided with a marked decrease in growth rate (Congdon and van Loben Sels 1991); in Nova Scotia turtles in their late teens (17 years) have similar growth rates (CL) as turtles aged 6 (Chapter 1), and a plateau in growth rate is not apparent by age 20 (Figures 7a and 7b).

My results suggest that this population has an extended juvenile stage and that individuals reach sexual maturity much later than in other populations (Table 9). While the ongoing mark-recapture programme has confirmed that turtles in Kejimkujik National Park are long lived (Herman *et al.* 1995), and that their reproductive lifespan is long, there is no evidence that their overall lifespan is longer than elsewhere. Thus, turtles in Nova Scotia could have a shorter reproductive lifespan, and hence a lower lifetime reproductive potential than turtles in other populations.

Despite insufficient information on inter-annual clutch frequency, data on annual and lifetime reproductive potentials support the contention that reproduction is constrained in Nova Scotia. However, in the absence of dietary analyses, and comparative data of habitat quality and microclimate, it is difficult to attribute the constraint to any environmental variable. Also, it is unlikely that the effects of a single variable such as temperature could be measured in a wild population, for despite the recognized physiological consequences of habitat selection on the ecological performance and demography of poikilotherms, the interactions between microclimate, physiology, behaviour and performance are often subtle and indirect (Huey 1991). Although one could argue that temperature ultimately limits reproductive potential by mediating appetite, food acquisition and digestive efficiency, which in turn influence clutch size, clutch frequency and rates of growth and maturation, it is important to recognize that the influence of the thermal microclimate on reproductive potential is indirect. Though reproductive potential appears constrained, it cannot be concluded that temperature is the limiting factor. This, however, does not preclude the thermal dependence of reproduction.

Whereas reproductive potential describes the number of offspring (eggs) produced, reproductive success measures an individual's genetic contribution to the next generation. Because measuring actual reproductive success is difficult and impractical in many circumstances, other population parameters are considered suitable indices (Howard 1979). In vivi- and oviviparous organisms reproductive success is estimated by the number of offspring born; in oviparous species, it is estimated by hatching success (Howard 1979). I argue that for oviparous species that bury their eggs, emergence from the nest cavity is analogous to 'birth' in vivi- and oviviparous species. Hatchling quality is also relevant because it influences survivorship (Howard 1979). Thus, hatching success, emergence success and hatchling quality should be considered when estimating reproductive success in turtles.

Power (1989) proposed that, in Nova Scotia, egg and hatchling survivorship are constrained by the cool climate. However, the small sample and short-term study detracted from his argument. I compiled data from earlier sources, with those collected during my study (Chapter 1) to provide sufficient long-term data to generalize about reproductive success in this population.

In Nova Scotia, Blanding's turtles suffer high levels of partial and complete nest failure (Table 5, Table 9). Though the proportion of productive nests in Nova Scotia does not differ from elsewhere, fewer nests have a 100% hatch, and within productive nests, fewer eggs produced viable offspring (*i.e.* hatched or produced live hatchlings) (Tables 5 and 9). Considering only unhatched eggs and dead embryos, egg failure in Nova Scotia ranges from 17% to 58%; on average 38% of eggs fail due to causes other than predation (Table 5). In addition to hatchlings that die prior to excavation (this study, Morrison 1993, Power 1989), numerous live hatchlings fail to emerge from the nest. Were neonates physiologically capable of withstanding terrestrial hibernation, it is unlikely that hatchlings remaining in the nest cavity would survive ice scouring and flooding over the winter (Chapter 2). That is, while these successfully hatch, their failure to emerge from the nest prior to winter nullifies their contribution to reproductive success.

Including hatched but unemerged hatchlings as 'failed eggs' in calculations, overall egg failure in Nova Scotia ranges from 29% to 87%; on average 57% of eggs fail due to causes other than predation (Table 5). If the effects of flooding are discounted (*e.g.* consider data from 1994 and 1995 only, Table 5) egg failure (again, including hatchlings that fail to emerge from the nest) is between 29% and 37%. In addition to high egg failure, hatchling characteristics which have not been reported from other populations, such as scute deformities (Appendix E), large yolk sacs and paralysis, indicate that neonates in Nova Scotia are of poor quality. Thus, hatching and emergence success in Nova Scotia are much lower than has been reported from elsewhere (Table 5, Table 9), neonates appear to be of lower quality, and post-emergence survivorship may be lower than in other populations.

Why is reproductive success low in Nova Scotia?

Gutzke and Packard (1987) demonstrated that temperature affects hatching success in Blanding's turtles. In some species, eggs incubated at low temperatures also produce hatchlings of poor quality (*e.g.* deformed, edematous, lethargic, uncoordinated and with large residual yolk sacs), some of which may be too weak to emerge from the egg, let alone from the nest (Lewis-Winokur and Winokur 1995, Bobyn and Brooks 1994, Gutzke *et al.* 1987). One could argue that hatching and emergence success and hatchling quality are reduced in Nova Scotia as a result of poor thermal conditions experienced by developing embryos. However, the influence of other variables must not be ignored.

For instance, egg viability may be low because of poor maternal nutrition (Noble 1991, White 1991), infertility, the effects of disease and pollution (Bobyn and Brooks 1994) or poor drainage at nest sites (Kraemer and Bell 1980); emergence success may be reduced because nesting substrates in Nova Scotia are not as fine as elsewhere (Chapter 1) and hatchlings have more difficulty digging in coarse (Figure 6) and compacted substrates (Chapter 1, Peters *et al.* 1994). Hatchling deformities may arise from hydric stress (Lynn and Ullrich 1950) or as a consequence of pollution (Bobyn and Brooks 1994). These interactions would obscure the direct effects of temperature. Regardless, there are sufficient data to examine temperature's direct influences on reproductive success, and to show that reproductive success is compromised by low summer temperatures.

First, though the nesting season is similar to those reported from other populations (Tables 1 , 2 and 9), in Nova Scotia the peak in nesting activity occurs in the latter part of June (Figure 2), about a week later than in other populations (Table 9). The variable onset and peak in nesting activity between years in Nova Scotia (Figure 2) is suggestive of an environmental response. In snapping turtles (*Chelydra serpentina*) from north-central Ontario, Obbard and Brooks (1987) found that nesting was initiated earlier when water was warm in spring. Similarly, in Illinois, Thornhill (1982) found that the onset of nesting in red- eared turtles (*Chrysemys scripta elegans*) inhabiting an artificially warm lake (*i.e.* receiving heated effluent from a power-plant) was earlier than in a nearby unheated lake. Congdon *et al.* (1983) found that the onset of nesting by Blanding's turtles in Michigan was significantly related to air temperatures in April. Likely, the onset of nesting by Blanding's turtles in Nova Scotia is in response to spring temperatures; the late peak presumably reflects the cooler climate.

Second, the incubation interval in Nova Scotia is between 10 and 20 days longer than in other populations (Table 9). Incubation lasts no less than 82 days, and frequently lasts close to 100 days (Tables 4 and 10) such that hatchlings in Nova Scotia emerge in September and October (Table 5), if at all (this study 1996, Morrison 1992). Blanding's turtle eggs are only moderately affected by the hydric conditions during incubation (Packard *et al.* 1982), but hatching success, incubation time, and hatchling condition are affected by temperature (Gutzke and Packard 1987). Although this relationship is not linear, cooler incubation temperatures increase the time required for the completion of embryonic development (Deeming and Ferguson 1991, Gutzke and Packard 1987).

The late season and cool temperatures in spring result in relatively late nesting for the majority of females in the Nova Scotia population. In turn, late nesting shortens the interval available for the completion of embryonic development increasing the likelihood that late stage embryos will be exposed to low, autumn temperature. The consequences of this could be arrested development, embryonic mortality (Bobyn and Brooks 1994), failure to hatch because of lethargy (Lewis-Winokur and Winokur 1995), and / or failure to emerge from the nest because of thermal constraints on mobility (Bobyn and Brooks 1994). Though the duration of incubation varies among years in Nova Scotia (Tables 4, 5 and 10) eggs sometimes fail to hatch before late October (Table 10). The short season, late nesting, and the extended duration of incubation have serious repercussions for reproductive success in this population.

In an investigation of nest site selection in painted turtles (*Chrysemys picta*), Schwartzkopf and Brooks (1987) found that nest sites were warmer than randomly chosen sites in the immediate area. Rejecting the suggestion that nest site selection is a means by which female turtles influence hatchling sex ratio[13] (Janzen 1994, Vogt and Bull 1982), at least in northern populations, these authors argued that at high latitudes female turtles select sites that are conducive to the successful completion of embryonic development. Given the high critical thermal minimum for successful incubation of Blanding's

---

[13] In many turtle species, including *Emydoidea blandingii*, sex determination is controlled by incubation temperature during embryonic development. Despite discrepancies between results of laboratory and field studies such studies have contributed greatly to the understanding of turtle evolution and ecology (Rhen and Lang 1995, Lewis-Winokur and Winokur 1995, Janzen 1994, Servan *et al.* 1989, Schwartzkopf and Brooks 1987, Bull 1985, Schwartzkopf and Brooks 1985, Vogt and Bull 1984, Vogt and Bull 1982, Bull and Vogt 1979). In Blanding's turtles females develop at high temperatures (> 30 °C) and males are produced at lower temperatures (< 28 °C) (Gutzke and Packard 1987).

turtle eggs (Gutzke and Packard 1987), and that the rate of incubation is accelerated at higher temperatures (Gutzke and Packard 1987, Deeming and Ferguson 1991), a site's thermal microclimate should reflect its suitability for nesting (Herman *et al.* submitted). My finding, that Blanding's turtle nest sites were significantly warmer than their paired sites in the non-nesting section of the beach (n = 13 pairs, P(t ≥ 1.356) 0.10) (Table 8), supports this contention.

Though my data do not suggest that thermal cues directly influence nest site selection as has been suggested for eastern mud turtles (*Kinosternon subrubrum*), Florida cooters (*Pseudemys floridana*) (Brodie *et al.* 1996), and western painted turtles (Janzen 1994), and has been demonstrated in the marine turtle, *Caretta caretta* (Stoneburner and Richardson 1981), it is possible that female turtles are able to detect thermal gradients by 'sand sniffing' (Chapter 1) and resting the throat on the substrate (Morrison, pers. comm.) (Stoneburner and Richardson 1981). Were Blanding's turtles able to detect thermal gradients and use them to evaluate a potential nest site, likely, thermal properties would be only part of a suite of cues used to assess the suitability of sites within beaches. I propose this because of the length of time gravid females devote to 'searching' (Chapter 1, Appendix B) and the apparent selection for slope (Figure 4) and aspect (Figure 5). As well, though no pattern of substrate selection is apparent from analyses of superficial substrates (Appendix F), nor from sieving analyses (Figure 6), substrates could prevent nesting in some areas that are otherwise 'suitable'. On a larger scale, females may choose beaches based on their proximity to warm, sheltered coves with exposed basking sites (Figures 3a, 3b, 3c), or the beach's accessibility and proximity to the female's home range. Alternatively, female Blanding's turtles may return to their natal beach to nest as has been suggested for sea turtles (Carr 1986). Regardless of the mechanism, in Nova Scotia, Blanding's turtles use relatively warm sites for nesting, and I concur with Herman *et al.* (submitted) that female nesting behaviour is influenced by thermal microclimate.

The results of this study support the postulates that Blanding's turtle reproduction is constrained in Nova Scotia relative to populations elsewhere, and that temperature is the primary factor limiting reproduction, especially reproductive success (Herman *et al.* 1995, Power 1989). The effects of the thermal environment on incubation are well documented in turtles, and temperature is known to influence, among other things, incubation time, metabolism, sex ratio, hatching success, size at hatching, and post-hatching growth, performance and survival (Lewis-Winokur and Winokur 1995, Rhen and Lang 1995, Bobyn and Brooks 1994, Janzen 1994, 1993, Deeming and Ferguson 1991, Servan *et al.* 1989, Gutzke and Packard 1987, Gutzke *et al.* 1987, Bull 1985, Vogt and Bull 1982, Bull and Vogt 1979, Ewert 1979, Yntema 1968). Thermal environment also influences juvenile and adult growth rates, hormonal and activity cycles, appetite, digestive efficiency, clutch size and clutch frequency (Avery *et al.* 1993, Noble 1991, Congdon 1989, Hammond *et al.* 1988, Obbard and Brooks 1987, Ewert 1985, Ganzhorn and Light 1983, Ho *et al.* 1982, Thornhill 1982, Parmenter 1980). Numerous authors have proposed that the northern distribution of many turtle species is limited by the cumulative effects of short growing season and low temperature on reproduction and recruitment (Bobyn and Brooks 1994, Gutzke and Packard 1987, Allard 1935). It appears that the distribution of Blanding's turtles in Nova Scotia is similarly restricted, as was suggested by Bleakney (1958).

Conclusions

Throughout this thesis I have repeated the assertion that wildlife managers need a greater understanding of the ecology of Blanding's turtles in Nova Scotia if the recovery of this threatened population is to be successful. As of yet, I have only used this claim to justify the research, and have not suggested how the results might be put to use. In this last section, I briefly summarize some of the practical applications of my work.

First, I feel the nest screening programme should be continued, at least until we have a better understanding of predation pressure on eggs, and I suggest incorporating additional practices into the headstarting programme. Incubating some eggs under controlled laboratory conditions would eliminate the risk of flooding, and would facilitate the enhancement of the incubation environment. Incubation time, hatching success and hatchling quality could then be optimized, and if deemed necessary, hatchling sex ratio could be manipulated. Also, rearing hatchlings over winter in captivity and releasing them in the spring would be beneficial; such a programme would mitigate the effects of predation of hatchlings, and if sexual maturation is related to juvenile growth rate, recruitment rates could be increased.

Second, nesting beaches and the surrounding terrestrial habitat must be protected against development and habitat fragmentation. Within Kejimkujik National Park, human access to important nesting centres such as Glode Island and Heber Meadow beaches should be regulated. Specifically, disturbance must be minimized during the nesting season *and* during hatchling emergence.

Finally, though the focus of this project has been the Blanding's turtle population of Nova Scotia, the results are broadly applicable to other populations, and to other freshwater turtle species. Future research should include rates of hatching success and hatchling emergence in discussions of reproductive success and life histories. Attempts should be made to identify critical features and locations of hatchling hibernacula, particularly for freshwater turtles that 'typically' nest inland. Post-emergence orientation mechanisms and neonatal behaviour are poorly understood for freshwater turtles and their study has been neglected. If hatchling freshwater turtles use similar orientation mechanisms as marine species, what are the impacts of using inland sites (*e.g.* roadsides)? What contribution do these nests make to reproductive success? Do hatchlings become disoriented by topography, vegetation or the lack of open water? Are eggs exposed to extremes in temperature that might reduce hatching success or hatchling quality? Are the eggs more prone to desiccation? Does substrate compactness discourage hatchling emergence? What impact does road salting have on overwintering success for neonates hibernating in roadside nests, and for turtles that hibernate in nearby flooded habitat? Clearly, there are many questions that remain to be answered. While turtles have proven ideal model organisms for testing life history theories, in future, researchers should endeavour to address questions with greater practical relevance for conservation.

Literature cited

Able, K.P. 1991. Common themes and variations in animal orientation systems. Amer. Zool. 31: 157 - 167.

Allard, H.A. 1935. The natural history of the box turtle. Scient. Mon., N.Y. 41: 325 - 338. Cited in Packard G.C., and M.J. Packard. 1988. The physiological ecology of reptilian eggs and embryos. IN Biology of the Reptilia vol. 16. C. Gans (Ed.). Alan R. Liss, Inc. NY. pp. 523 - 605.

Anderson, P.K. 1958. The photic responses and water-approach behavior of hatchling turtles. Copeia 1958: 211 - 215.

Ashley, E.P. and J.T. Robinson. 1996. Road mortality of amphibians, reptiles and other wildlife on the Long Point Causeway, Lake Erie, Ontario. Can. Field-Nat. 110: 403 - 412.

Avery, H.W., J.R. Spotila, J.D. Congdon, R.U. Fischer Jr., E.A. Standora, S.B. Avery. 1993. Roles of diet protein and temperature in the growth and nutritional energetics of juvenile slider turtles, *Trachemys scripta*. Physiol. Zool. 66: 902 - 925.

Baskerville, G.L., and P. Emin. 1969. Rapid estimation of heat accumulated from maximum and minimum temperatures. Ecology 50: 514 - 517.

Batschelet, E. 1981. Circular Statistics in Biology. Academic Press, New York.

Batschelet, E. 1965. Statistical Methods for the Analysis of Problems in Animal Orientation and Certain Biological Rhythms. The American Institute of Biological Sciences, Library of Congress 65-26076, Washington, D.C.

Bleakney, J.S. 1976. Literature review related to the presence of Blanding's turtle in Kejimkujik National Park. Unpublished.

Bleakney, J.S. 1963. Notes on the distribution and life histories of turtles in Nova Scotia. Can. Field-Nat. 77: 67 - 76.

Bleakney, J.S. 1958. A Zoogeographic study of the amphibians and reptiles of eastern Canada. National Museum of Canada, Bulletin 155.

Bleakney, J.S. 1958b. The significance of turtle bones from archeological sites in southern Ontario and Quebec. Can. Field-Nat. 72: 1 - 5.

Brecke, B. and J.J. Moriarty. 1989. *Emydoidea blandingi* (Blanding's Turtle) longevity. Herp. Review 20: 53.

Briston, C.A. and W.H.N. Gutzke. 1993. Antipredator mechanisms of hatchling freshwater turtles. Copeia 1993: 435 - 440.

Brodie, J.R., K.R. Smith and V.J.Burke. 1996. A comparison of diel temperature and nest site selection of two sympatric species of freshwater turtles. Am. Midl. Nat. 136: 181 - 186.

Brown, J.R. 1927. A Blanding's turtle lays its eggs. Can. Field-Nat. 41:185.

Brooks, R.J., C.M. Shilton, G.P. Brown, N.W.S. Quinn. 1991. Body size, age distribution, and reproduction in a northern population of wood turtles (*Clemmys insculpta*). Can. J. Zool. 70: 462 - 469.

Brooks, R.J., D.A. Galbraith, E.G Nancekivell and C.A Bishop. 1988. Development of management guidelines for snapping turtles. In

Management of amphibians, reptiles, and small mammals in North America. Proceedings of the Symposium (July 19 - 21, 1988. Flagstaf, Arizona). USDA Forest Service General Technical Report RM - 166

Bull, J.J. 1985. Sex ratio and nest temperature in turtles: comparing field and laboratory data. Ecology 66: 1115 - 1122.

Bull, J.J., and R.C. Vogt. 1979. Temperature-dependent sex determination in turtles. Science 206: 1186 - 1188.

Butler, B.O. and T.E. Graham. 1995. Early post-emergent behavior and habitat selection in hatchling Blanding's turtles, *Emydoidea blandingii,* in Massachusetts. Chelonian Conservation and Biology 1: 187 - 196.

Butler, B.O. and T.E. Graham.1993. Tracking hatchling Blanding' s turtles with fluorescent pigments. Herp. Review 24: 21 - 22.

Carr, A. 1986. Rips, FADS, and little loggerheads. BioScience 36: 92 - 100.

Churchfield, S. 1990. The Natural History of Shrews. Comstock Publishing Associates. New York. xiv + 178 pp.

Churchfield, S. 1980. Subterranean foraging and burrowing activity of the common shrew. Acta theriol. 25: 451 - 459.

Cimon, A. 1986. Les reptiles du Québec, bio-écologie des espèces et problèmatique de conservation des habitats. MLCP. Service des études écologique. 93 pp. In S. Matte (1989). Rapport sur la situation de la tortue mouchetée, *Emydoidea blandingi.* Report submitted to

COSEWIC by: Société d' histoire naturelle de la vallée du Saint-Laurent.

Claussen, D.L., P.M. Daniel, S. Jiang, and N. Adams. 1991. Hibernation in the Eastern box turtle, *Terrapene c. carolina.* J. Herpetol. 25: 334 -341.

Cochran, P.A. and J.D. Lyons. 1986. New distributional records for Wisconsin amphibians and reptiles. Wisc. Acad. Sci., Arts and Letters 74: 138 - 141.

Compton, R.R. 1985. Geology in the field. John Wiley and Sons, NY.

Congdon, J.D. 1989. Proximate and evolutionary constraints on energy relations of reptiles. Physiol. Zool. 62: 356 - 373.

Congdon, J.D., A.E. Dunham and R.C. van Loben Sels. 1993. Delayed sexual maturity and demographics of Blanding's turtles (*Emydoidea blandingii*): Implications for conservation and management of long-lived organisms. Conservation Biol. 7: 826 - 833.

Congdon, J.D., S.W. Gotte, and R.W. McDiarmid. 1992. Ontogenic changes in habitat use by juvenile turtles, *Chelydra serpentina* and *Chrysemys picta.* Can. Field-Nat. 106: 241-248.

Congdon, J.D., D.W. Tinkle, G.L. Breitenbach and R.C. van Loben Sels. 1983. Nesting ecology and hatching success in the turtle *Emydoidea blandingii.* Herpetologica 39: 417 - 429.

Congdon, J.D., and R.C. van Loben Sels. 1993. Relationships of reproductive traits and body size with attainment of sexual maturity and age in

Blanding's turtles (*Emydoidea blandingi*). J. evol. Biol. 6: 547 - 557.

Congdon, J.D. and R.C. van Loben Sels. 1991. Growth and body size in Blanding's turtles (*Emydoidea blandingi*): relationship to reproduction. Can. J. Zool. 69: 239 - 245.

Cook, F.R. 1984. Introduction to Canadian amphibians and reptiles. Ed. P.Williams. National Museum of Natural Sciences. Ottawa, Canada.

Cooper, W.S. 1981. Natural decision theory: A general formalism for the analysis of evolved characteristics. J. Theor. Biol. 92: 401 - 415.

Cooper, W.S., and Kaplan, R.H. 1982. Adaptive "coin-flipping": a decision-theoretic examination of natural selection for random individual variation. J. Theor. Biol. 94: 135 - 151.

Deeming, D.C., and M.W.J. Ferguson. 1991. Physiological effects of incubation temperature on embryonic development in reptiles and birds. IN Egg incubation: its effects on embryonic development in birds and reptiles. Eds. D.C. Deeming and M.W.J. Ferguson. Cambridge University Press, NY. Pp. 147 - 171.

DePari, J.A., Linck, M.H., and Graham, T.E. 1987. Clutch size of the Blanding's turtle, *Emydoidea blandingii*, in Massachusetts. Can. Field-Nat. 101: 440 - 442.

Dobson, R.B. 1970. a field study of the Blanding's turtle (*Emydoidea blandingii*) in Kejimkujik National Park, Nova Scotia. Unpublished draft report, Parks Canada Atlantic Regional Office Library.

Drysdale, C.D. 1983. A resource analysis and management plan for the Blanding's turtle (*Emydoidea blandingii*) in Kejimkujik National Park. Parks Canada, Atlantic Regional Office Library.

Ehrenfeld, D.W. 1979. Behaviour associated with nesting. IN Turtles: perspectives and research. Eds. M. Harless and H. Morlock. John Wiley and Sons, Inc. NY. pp 417 - 434.

Ehrenfeld, D.W. 1968. The role of vision in the sea-finding orientation of the green turtle (*Chelonia mydas*). 2. Orientation mechanism and range of spectral sensitivity. Animal Behavior 16: 281 - 287.

Ehrenfeld, D.W. and A. Carr. 1967. The role of vision in the sea finding orientation of the green turtle (*Chelonia mydas*). Animal Behavior 15: 25 - 36.

Ernst, C.H. 1973. The distribution of turtles in Minnesota. J.Herpetol. 7: 42 - 47.

Ernst, C. H., and R.W. Barbour. 1989. Turtles of the world. Ed. N. Dutro. Smithsonian Institution Press, Washington.

Ewert, M. A. 1979. The embryo and its egg: development and natural history. IN Turtles: perspectives and research. John Wiley and sons. New York. pp. 333 - 413.

Ewert, M. A. 1985. Embryology of turtles. IN Biology of the Reptilia (A) vol. 14. Ed. C. Gans. John Wiley and Sons, Inc. NY. pp. 77 - 267.

French, T.W. 1986. Archaeological evidence of *Emydoidea blandingii* in Maine. Herp. Review 17: 40.

Fritz, W.J., and J.N. Moore. 1988. Basics of physical stratigraphy and sedimentology. John Wiley and Sons, Inc. NY. p. 46.

Ganzhorn, D., and P. Light. 1983. Regulation of seasonal gonadal cycles by temperature in the painted turtle, *Chrysemys picta*. Copeia 1983: 347 - 358.

Gibbons, J.W. 1982. Reproductive patterns in freshwater turtles. Herpetologica 38: 222 - 227.

Gibbons, J.W., and J.L.Greene. 1990. Reproduction in the slider and other species of turtle. IN Life history and ecology of the slider turtle. Ed. R. Sheffield. Smithsonian Institution. pp. 124 - 134.

Gibbons, J.W. and D.H. Nelson. 1978. The evolutionary significance of delayed emergence from the nest by hatchling turtles. Evolution 32: 297 - 303.

Gibbons, J.W. 1968 a. Reproductive potential, activity, and cycles in the painted turtle, *Chrysemys picta* Ecology 49: 399 - 409.

Gibbons, J.W. 1968 b. Population structure and survivorship in the painted turtle, *Chrysemys picta*. Copeia 1968: 260 - 268.

Godfrey, M.H., and R. Barreto. 1995. Beach vegetation and sea finding orientation of turtle hatchlings. Biological Conservation 74: 29 - 32.

Graham, T.E. 1986. *Emydoidea blandingii* (Blanding's turtle). USA: Massachusetts: Bristol Co. Hockmock Swamp. Herp. Review 17: 50.

Graham, T. E. 1979. Life history techniques. IN Turtles: perspectives and research. John Wiley and sons. New York. pp 73 - 125.

Graham, T.E. and T.S. Doyle. 1977. Growth and population characteristics of Blanding's turtle, *Emydoidea blandingii*, in Massachusetts. Herpetologica 33: 410 - 414.

Graham, T.E. and T.S. Doyle. 1973. The Blanding's turtle, *Emydoidea blandingii* Holbrook, in Maine. Hiss News Jour. 1: 29.

Graham, T.E., J.E. Forsberg and J.J. Albright. 1987. Updated distribution of the Blanding's turtle, *Emydoidea blandingii* in Maine. Bull. Mass. Herp. Soc. 23: 119 -121.

Gutzke, W.H.N., and G.C. Packard. 1987. The influence of temperature on eggs and hatchlings of Blanding's turtles, *Emydoidea blandingii*. J. Herpetol. 21: 161 - 163.

Gutzke, W.H.N., G.C. Packard, M.J. Packard, and T.J. Boardman. 1987. Influence of the hydric and thermal environments on eggs and hatchlings of painted turtles (*Chrysemys picta*). Herpetologica 43: 393 - 404.

Hammond, K.A., J.R. Spotila, and E.A. Standora. 1988. Basking behavior of the turtle *Pseudemys scripta*: effects of digestive state, acclimation temperature, sex, and season. Physiol. Zool. 61: 69 - 77.

Heppell, S.S., L.B. Crowder, and D.T. Crouse. 1996. Models to evaluate headstarting as a management tool for long-lived turtles. Ecological Applications 6: 556 - 565.

Herman, T.B., T.D Power, and B.R. Eaton. 1995. Status of Blanding's Turtles, *Emydoidea blandingii,* in Nova Scotia, Canada. Can. Field-Nat. 109: 182 - 191.

Herman, T.B., J.S. Bleakney, J.S. Boates, C. Drysdale, J. Gilhen, I.P. Morrison, T. Power, K.L. Standing, and M. Elderkin (submitted). National recovery plan for the Blanding's turtle (Nova Scotia Population). Ottawa: Recovery of Nationally Endangered Wildlife Committee.

Ho. S.-M., S. Kleis, R.McPherson, G.J. Heisemann, and I.P. Callard. 1982. Regulation of vitellogenesis in reptiles. Herpetologica 38: 40 - 50.

Horrocks, J.A., and N.McA. Scott. 1991. Nest site location and nest success in the hawksbill turtle *Eretmochelys imbricata* in Barbados, West Indies. Mar. Ecol. Prog. Ser. 69: 1 - 8.

Howard, R.D. 1979. Estimating reproductive success in natural populations. Am. Nat. 114: 221 - 231.

Hutchison, J.H. 1981. *Emydoidea* (Emydidae, Testudines) from the Barstovian (Miocene) of Nebraska. PaleoBios 37: 1 - 6.

Iverson, J.B. 1996. Geographic distribution: range extension for *Emydoidea blandingii.* Herp. Review 27: 150.

Iverson, J.B. 1991. Patterns of survivorship in turtles (order Testudines). Can. J. Zool. 69: 385 - 391.

Iverson, J.B. 1989. Nesting and parental care in the mud turtle, *Kinosternon flavescens*. Can. J. Zool. 68: 230 - 233.

Jackson, C.G. Jr., and J.M. Kaye. 1974. The occurrence of Blanding's turtle, *Emydoidea blandingii*, in the Late Pleistocene of Mississippi (Testudines: Testudinidae). Herpetologica 30: 417 - 419.

Janzen, F.J. 1994. Vegetational cover predicts the sex ratio of hatchling turtles in natural nests. Ecology 75: 1593 - 1599.

Janzen, F.J. 1993. The influence of incubation temperature and family on eggs, embryos, and hatchlings of the smooth softshell turtle (*Apalone mutica*). Physiol. Zool. 66: 349 - 373.

Janzen, F.J., G.L. Paukstis and E.D. Brodie III. 1992. Observations on basking behavior of hatchling turtles in the wild. J. Herpetol. 26: 217 - 219.

Klemens, H.W. 1993. Amphibians and reptiles of Connecticut and adjacent regions. State Geological and Natural History Survey of Connecticut. Bull. 112.

Kraemer, J.E., and R. Bell. 1980. Rain-induced mortality of eggs and hatchlings of Loggerhead sea turtles (*Caretta caretta*) on the Georgia coast. Herpetologica 36: 72 - 77.

Krumbein, W.C. 1941. Measurement and geological significance of shape and roundness of sedimentary particle. J. Sed. Petrol. 11: 64 -72.

Lefevre K. and R.J. Brooks. 1995. Effects of sex and body size on basking behavior in a northern population of the painted turtle, *Chrysemys picta*. Herpetologica 51: 217 - 224.

Lewis-Winokur, V. and R.M. Winokur. 1995. Incubation temperature affects sexual differentiation, incubation time and posthatching survival in desert tortoises (*Gopherus agassizi*). Can. J. Zool. 73: 2091 - 2097.

Lohmann, K.J., and C.M.F. Lohmann. 1996. Orientation and open-sea navigation in sea turtles. J. exp. Biol. 199: 73 - 81.

Lynn, W.G., and M.C. Ullrich. 1950. Experimental production of shell abnormalities in turtles. Copeia 1950: 253 - 262.

MacCulloch, R.D., and W.F. Weller. 1988. Some aspects of reproduction in a Lake Erie population of Blanding's turtle, *Emydoidea blandingii*. Can. J. Zool. 66: 2317 - 2319.

Matte, S. 1989. Rapport sur la situation de la tortue mouchetée, *Emydoidea blandingi*. Report submitted to COSEWIC by: Société d' histoire naturelle de la vallée du Saint-Laurent.

McCoy, C.J. 1973. Emydoidea. *E. blandingii*. Catalogue of American Amphibians and Reptiles 136: 1 - 4.

McMaster, N.L. 1996. Age structure, distribution, habitat selection and movement patterns of juvenile Blanding's turtles (*Emydoidea blandingii*) in Kejimkujik National Park, Nova Scotia. B.Sc. Honours thesis. Acadia University, Wolfville, Nova Scotia, Canada.

McMurray, I.T. 1984. A herpetofaunal study of Gatineau Park. Commission de la capitale national, Hull, 5 : 942 pp. In S. Matte (1989). Rapport sur la situation de la tortue mouchetée, *Emydoidea blandingi.* Report submitted to COSEWIC by: Société d' histoire naturelle de la vallée du Saint-Laurent.

McNeil, J. 1996. Post-emergent movement of hatchling Blanding's turtles (*Emydoidea blandingii* (Holbrook)) in Kejimkujik National Park, Nova Scotia. B.Sc. Honours thesis. Acadia University, Wolfville, Nova Scotia, Canada.

Mélançon, C. 1950. Membre à vie de la Société Zoologique. Inconnus et méconnus (amphibiens et reptiles de la province de Québec). La Société Zoologique de Québec Inc. 150 pp. In S. Matte (1989). Rapport sur la situation de la tortue mouchetée, *Emydoidea blandingi.* Report submitted to COSEWIC by: Société d' histoire naturelle de la vallée du Saint-Laurent.

Minckley, W.L. 1966. Coyote predation on aquatic turtles. J. Mammal. 47: 137.

Mockford, S. 1996. A genetic comparison of several populations of Blanding's turtle (*Emydoidea blandingii*). B.Sc. Honours thesis. Acadia University, Wolfville, Nova Scotia, Canada.

Morrison, I.P. 1993. Blanding's turtle monitoring report for Kejimkujik National Park. Resource Conservation Office, Kejimkujik National Park, Queens Co. Nova Scotia. 41 pp.

Morrison, I.P. 1992. Blanding's turtle (*Emydoidea blandingii*) monitoring report for Kejimkujik National Park. Resource Conservation Office, Kejimkujik National Park, Queens Co. Nova Scotia. 30 pp.

Noble, R.C. 1991. Comparative composition and utilization of yolk lipid by embryonic birds and reptiles. IN Egg incubation: its effects on embryonic development in birds and reptiles. Eds. D.C. Deeming and M.W.J. Ferguson. Cambridge University Press, NY. Pp. 17 - 28.

Obbard, M.E. and R.J. Brooks. 1987. Prediction of the onset of the annual nesting season of the common snapping turtle, *Chelydra serpentina*. Herpetologica 43: 324 - 328.

Obbard, M.E. and R.J. Brooks. 1978. Factors affecting basking in a northern population of the common snapping turtle, *Chelydra serpentina*. Can. J. Zool. 57: 435 - 440.

Oickle, D.J. 1997. An assessment of predation on turtle nests in relation to the spatial ecology of raccoons (*Procyon lotor*) in Kejimkujik National Park, Nova Scotia. B.Sc. Honours thesis. Acadia University, Wolfville, Nova Scotia, Canada.

Olson, R.E. 1987. Minnesota herpetological records. Bull. Maryland Herp. Soc. 23: 101 - 104.

Packard, G.C., and M.J. Packard. 1995. A review of the adaptive strategy used by hatchling painted turtles to survive cold. Herp. Review 26: 8 - 12.

Packard, G.C., and M.J. Packard. 1990. Patterns of survival at subzero temperatures by hatchling painted turtles and snapping turtles. J. exp. Zool. 254: 233 - 236.

Packard G.C., and M.J. Packard. 1988. The physiological ecology of reptilian eggs and embryos. IN Biology of the Reptilia vol. 16. C. Gans (Ed.). Alan R. Liss, Inc. NY. pp. 523 - 605.

Pappas, M.J., and B.J. Brecke. 1992. Habitat selection of juvenile Blanding's turtles, *Emydoidea blandingii*. J. Herpetol. 26: 233 - 234.

Parmenter, R.R. 1980. Effects of food availability and water temperature on the feeding ecology of pond sliders (*Chrysemys s. scripta*). Copeia 1980: 503 - 514.

Penney, D.G. 1974. Effects of prolonged diving anoxia on the turtle, *Pseudemys scripta elegans*. Comp. Biochem. Physiol. 47A: 933 - 941.

Peters, A., K.J.F. Verhoeven and H. Strijbosch. 1994. Hatching and emergence in the Turkish Mediterranean Loggerhead turtle, *Caretta caretta*: natural causes for egg and hatchling failure. Herpetologica 50: 369 - 373.

Petokas, P.J. 1986. Patterns of reproduction and growth in the freshwater turtle *Emydoidea blandingii*. Ph. D. Thesis. State Univ. New York, Binghamton (SUNY).

Petokas, P.J. and M.M. Alexander. 1981. Occurrence of the Blanding's turtle in northern New York. New York Fish and Game Journal 28: 119 - 129.

Petokas, P.J. and M.M. Alexander. 1980. Geographic distribution: *Emydoidea blandingii.* Herpetol. Rev.11: 14.

Petokas, P.J. and M.M. Alexander. 1978. Geographic distribution: *Emydoidea blandingii.* Herpetol. Rev. 9: 107.

Polisar, J. 1996. Reproductive biology of a flood-season nesting freshwater turtle of the northern neotropics: *Dermatemys mawii* in Belize. Chelonian Conservation and Biology 2: 13 - 25.

Power, T.D. 1989. Seasonal Movements and nesting ecology of a relict population of Blanding' s Turtle (*Emydoidea blandingii* (Holbrook)) in Nova Scotia. M. Sc. thesis. Acadia University. N.S. Canada.

Power, T.D., T.B. Herman and J. Kerekes. 1994. Water colour as a predictor of local distribution of Blanding's Turtle, *Emydoidea blandingii,* in Nova Scotia. Can. Field-Nat. 108: 17 - 21.

Pritchard, P.C.H. 1979. Taxonomy, evolution and zoogeography. IN Turtles: Perspectives and Research. Eds. M.Harless and H.Morlock. John Wiley and Sons, Inc., NY. pp. 1 - 42.

Rhen, T., and J.W. Lang. Phenotypic plasticity for growth in the common snapping turtle: effects of incubation temperature, clutch, and their interaction. Am. Nat. 146: 726 - 747.

Ross, D.A. 1989. Population ecology of painted and Blanding's turtles (*Chrysemys picta* and *Emydoidea blandingii*) in central Wisconsin. Wisc. Acad. Sci. Arts Lett. 77: 77 - 84.

Ross, D.A., and Anderson, R.K. 1990. Habitat use, movement, and nesting of *Emydoidea blandingii* in central Wisconsin. J. Herpetol. 24: 6 - 12

Roland, A.E. 1945. The Flora of Nova Scotia. IN Proceedings of Nova Scotian Institute of Science. Vol 21 (3). Truro Printing and Publishing Co. Ltd. NS.

Rowe, J.W. and E.O. Moll. 1991. A radiotelemetric study of activity and movements of the Blanding's turtle (*Emydoidea blandingii*) in northeastern Illinois. J. Herpetol. 25: 178 - 185.

Salmon, M., J. Wyneken, E. Fritz and M. Lucas. 1992. Seafinding by hatchling sea turtles: Role of brightness, silhouette and beach slope as orientation cues. Behaviour 122: 56 - 77.

Schwartzkopf, L., and R.J. Brooks. 1987. Nest-site selection and offspring sex ratio in painted turtles, *Chrysemys picta*. Copeia 1987: 53 - 61.

Servan, J., P. Zaborski, M. Dorizzi, and C. Pieau. 1989. Female-biased sex ratio in adults of the turtle *Emys orbicularis* at the northern limit of its distribution in France: a probable consequence of interaction of temperature with genotypic sex determination. Can. J. Zool. 67: 1279 - 1284.

Shure, D.J., Wilson, L.A., and Hochwender, C.. 1989. Predation on aposematic efts of *Notophthalmus viridescens*. J. Herpetol. 23: 437 - 439.

Sloan, K.N., K.A. Buhlmann, and J.E. Lovich. 1996. Stomach contents of commercially harvested adult alligator snapping turtles, *Macroclemys temminckii*. Chelonian Conservation and Biology 2: 96 - 99.

Spiess, A.E., and K.D. Sobolik. 1997. Blanding's turtle specimens from the Turner Farm archaeological site, North Haven, Maine. Herp. Review 28: 24 - 25.

Sneed, E.D., and R.L. Folk. 1958. Pebbles in the lower Colorado River Texas - a study in particle morphogenesis. J. Geol. 66: 114 - 150

Snyder, L.L. 1921. Some observations on Blanding's Turtle. Can. Field-Nat. 35: 17- 18.

Standing, K.L., I. P. Morrison and T.B. Herman. 1995. Notching scheme for hatchling Blanding' s turtles in Kejimkujik National Park. On file. Centre for Wildlife and Conservation Biology, Acadia University, Wolfville, N.S.

Stapp, P., Young, J.K., VandeWoude, S., and Van Horne, B. 1994. An evaluation of the pathological effects of fluorescent powder on deer mice (*Peromyscus maniculatis*). J. Mammal. 75: 704 - 709.

Stoneburner, D.L. and J.I. Richardson. 1981. Observations on the role of temperature in loggerhead turtle nest site selection. Copeia 1981: 238 - 241.

Storey, K.B., J.M. Storey, S.P.J. Brooks, T.A. Churchill, and R.J. Brooks. 1988. Hatchling turtles survive freezing during winter hibernation. Proc.Natl. Acad. Sci. USA. 85: 8350 - 8354.

Temple, S.A. 1987. Predation on turtle nests increases near ecological edges. Copeia 1987: 250 - 252.

Thexton, R.D. and H. Mallet. 1979. Blanding's turtle population in Kejimkujik National Park and immediate area 1977 - 79. Parks Canada. Kejimkujik National Park, Caledonia, Queens Co. Nova Scotia.

Thornhill, G.M. 1982. Comparative reproduction of the turtle, *Chrysemys scipta elegans,* in heated and natural lakes. J.Herpetol. 16: 347 - 353.

Townbridge, A. C. (Ed.). 1962. Dictionary of geological terms. The National academy of Sciences for the American Geological Institute. Dolphin Books, Doubleday and Co., Inc. NY.

Ultsch, G.R., R.W. Hanley, and T. R. Bauman. 1985. Responses to anoxia during simulated hibernation in northern and southern painted turtles. Ecology 66: 388 - 395.

van Devender, T.R., and J.E. King. 1975. Fossil Blanding's turtles , *Emydoidea blandingi* (Holbrook) and the late Pleistocene vegetation of western Missouri. Herpetologica 31: 208 - 212. In S. Matte (1989). Rapport sur la situation de la tortue mouchetée, *Emydoidea blandingi.* Report submitted to COSEWIC by: Société d' histoire naturelle de la vallée du Saint-Laurent.

Vogt, R.C., and J.J. Bull. 1984. Ecology of hatchling sex ratio in map turtles. Ecology 65: 582 - 587.

Vogt, R.C., and J.J. Bull. 1982. Temperature controlled sex-determination in turtles: ecological and behavioral aspects. Herpetologica 38: 156 - 164.

Weller, W.F. and M.J. Oldham. eds. 1988. Ontario Herpetofaunal Summary 1986. Ontario Field Naturalists. 221 pp.

Weller, W. 1971 - 72. Preliminary report of Blanding's turtle in Kejimkujik National Park. Unpubl. Parks Canada. Kejimkujik National Park, Caledonia, Queens Co. Nova Scotia. IN Power, T.D. 1989.

White, H.B. III. 1991. Maternal diet, maternal proteins and egg quality. IN Egg incubation: its effects on embryonic development in birds and reptiles. Eds. D.C. Deeming and M.W.J. Ferguson. Cambridge University Press, NY. Pp. 1 - 15.

Witherington, B.E., and Bjorndal, K.A. 1991. Influences of wavelength and intensity on hatchling sea turtle phototaxis: implications for sea-finding behavior. Copeia 1991: 1060 - 1069.

Yntema, C.L. 1968. A series of stages in the embryonic development of *Chelydra serpentina*. J. Morphol. 125: 219 - 252.

Zar, J.H. 1984. Biostatistical Analysis. Second Edition. Prentice Hall, Englewood Cliffs, New Jersey.

Table 1. Historical records of Blanding's turtle nesting activity in Kejimkujik National Park, Nova Scotia.

Year	Date nesting was observed	Source
1959	June 30	Bleakney 1963
1961	June 20	Bleakney 1976
1968	June 8 - 24	Dobson 1970, in Power 1989
1969-77	June 8 (1970) -July 2 (1971)	Thexton and Mallet 1979
1979	June 14	Park records
1980	June 20 - 26	Park records
1982	June 26	Park records
1983	June 22	Park records
1984	June 24	Park records
1987	June 19 - 24	Power 1989
1988	June 15 - 24	Power 1989
1992	June 14	Morrison 1992
1993	June 17- July 2	Morrison 1993
1994	June 11*- 25	This study
1995	June 16 - 29	This study
1996	June 12 - July 5	This study

* Nest found after predation

Table 2. Peak of nesting activity (completed nests) for Blanding's turtles in Kejimkujik National Park, Nova Scotia.

Year	Day	Source
1987	June 19	Power 1989
1988	June 15	Power 1989
1992	June 20	Morrison 1992
1993	June 27	Morrison 1993
1994	June 18	This study
1995	June 25	This study
1996	June 24 - 27	This study

Table 3a. Blanding's turtles positively identified nesting in three consecutive years 1994, 1995 and 1996 in Kejimkujik National Park, Nova Scotia. Absolute clutch size (aCS) was determined during oviposition by counting deposited eggs; otherwise clutch size was estimated during nesting (eCSn) or from hatching and excavation records (eCSh).

Female	Year	Clutch size			Location
		aCS	eCSn	eCSh	
0-1,3	1994	12			Atkin's (I)
	1995		9+	11	Atkin's (I)
	1996	10			Atkin's (I)
0-10,0	1994		10	2+	Atkin's (I)
	1995	10			Atkin's (I)
	1996	11			Atkin's (I)
1,0-2	1994	7			Heber (I)
	1995		11	11	Heber (II)
	1996	11			Heber (II)
2,3-2	1994	11			Glode Is.
	1995			4+	Glode Is.
	1996		11+	8	Glode Is.
2,3-11	1994		15+	15	J-line Road
	1995	14			J-line Road
	1996	15			J-line Road
2,9-1	1994		11+	10	J-line Road
	1995	10			J-line Road
	1996	10			J-line Road
3,0-1	1994		14+	14	Heber (II)
	1995		11+	13	Heber (II)
	1996	7			Heber (III)
7,7-8,8	1994	10			Glode Is.
	1995	10			Glode Is.
	1996	10			Glode Is.
8,0-3	1994	7			Glode Is.
	1995	5			Glode Is.
	1996	4			Glode Is.

Table 3b. Blanding's turtles positively identified nesting in two of three years between 1994 and 1996 in Kejimkujik National Park, Nova Scotia. Absolute clutch size (aCS) was determined during oviposition by counting deposited eggs; otherwise clutch size was estimated during nesting (eCSn) or from hatching and excavation records (eCSh). One nest (*) was left to overwinter and was destroyed by ice action; clutch size was not determined.

Female	**Year**	**Clutch size**			**Location**
		aCS	eCSn	eCSh	
0-1,8	1994		10+	10	Glode Is.
	1996	10			Atkin's (I)
2,10-1	1994			•	Heber (II)
	1996	12			Heber (II)
8,0-9	1994	9			Atkin's (I)
	1995	10			Heber (II)
8-1,3	1994	13			Atkin's (I)
	1996	12			Atkin's (I)
9-0,11	1994	11			Atkin's (I)
	1996	11			Atkin's (I)
9-3,11	1995		14+	15	Atkin's (I)
	1996	14			Atkin's (I)

Table 3c. Blanding's turtles positively identified nesting once between 1994 and 1996 in Kejimkujik National Park, Nova Scotia. Absolute clutch size (aCS) was determined during oviposition by counting deposited eggs; otherwise clutch size was estimated during nesting (eCSn) or from hatching and excavation records (eCSh). One nest (*) was left to overwinter and was destroyed by ice action; clutch size was not determined. Clutch size for one nest (**) was estimated after predation.

Female	Year	Clutch size aCS	 eCSn	 eCSh	Location
0-1,0	1995			4+**	Eelweir Road
0-3,8	1996	12			Glode Is.
1,0-0	1995	14			Peter Point
2,10-2	1995	12			Heber (II)
2,10-8	1994	12			Atkin's (I)
2,10-9	1996	9			Heber (II)
3,3-3,4	1995		10	10	Glode Is.
8-1,10	1995		5	3+	Glode Is.
8-1,8	1996	8			Atkin's (II)
10,0-2	1996	9			Glode Is.
10,0-8	1994			*	Glode Is.
10,0-9	1996	11			Glode Is.
11,0-2	1996	10			Glode Is.
Unknown	1994		11+	11	Atkin's (I)
Unknown	1996	9			Atkin's (II)

Table 4. Incubation interval (days) for Blanding's turtle eggs in natural nests in Kejimkujik National Park, Nova Scotia.

	1994	1995	1996
O-E_1			
mean	94.5	90.1	107
range	83 - 121	82 - 106	107
n, SD	11, 11.4	12, 6.3	2, ---
O-E_2			
mean	---	---	108
range	98 - 123	93 - 128*	101 - 112
n, SD	2, ---	2, ---	5, 4.8
O-E_3			
mean	---	---	111
range	---	---	91 - 137
n, SD	---	---	3, 23.7

O-E_1 Days elapsed from oviposition to emergence of first hatchling.
O-E_2 Days elapsed from oviposition to excavation of live hatchlings.
O-E_3 Days elapsed from oviposition to first signs of pipping.
n = no. of nests. *may have emerged on day 127 (Morrison, pers. comm.)

Table 5. Reproductive records for Blanding's turtles in Nova Scotia.

Source	j, k	l	l	l	
Year	(1987 - 1988)	1994	1995	1996	mean
Mean clutch size	9.4 j estimated	10.2 absolute	10.6 absolute	10.3 absolute	10.3 l
Productive nests min. 1 live hatchling	69% 9/13	93% 14/15	93% 14/15	50% 11/22	74% k,l 75% l
Nests 100% hatch	22% 2/9	8% 1/13 α	7% 1/14	18% 2/11	13% k, l 11% l
Non viable eggs */ productive nest	3.2 λ ψ 3.1 j, ϖ	2.2	1.4	1.8	1.8 ψ, l
Nest faillure due to causes other than predation	31% 4/13	6.6% 1/15	6.6% 1/15	50% 11/22	26% k, l 25% l
Overall egg failure Causes other than predation	56%	27%*	17%*	58%*	38% ψ, l
(* / total)	78 /140**	36/132	24/140	126/216	176/479 l
(* + live excavated / total)	—	49/132 (37%)	41/140 (29%)	189/216 (87%)	279/488 (57%)
Incubation (days) ϕ					
mean	95.1	94.5	90.1	107	93.4 l
range	85 - 105	83 - 121	82 - 106	107	82 -121
Hatchling emergence (natural)					
range	Sept. 11 - Oct. 7	Sept. 6 - Oct.19	Sept.13 - Oct. 25	Oct. 2 - 8	Sept. 6- Oct. 25
most		Sept.13 -19	Sept.14 -19	—	

ψ This is likely an underestimate because emergence was very late, and numerous hatchlings died shortly after emergence.

* Unhatched eggs + excavate dead hatchlings

** (77 unhatched eggs + 1 excavated dead hatchling)/estimated clutch size

ϕ Oviposition to 1st emergence

λ Recalculation from Power 1989:
unhatched eggs + hatchlings dead at excavation/ productive nest.

ϖ Unhatched eggs (only)/productive nest

j Herman *et al.* 1995 k Power 1989 l This study

Table 6. Hatchling Blanding's turtle orientation with respect to water nearest the nest (release point). Data collected from a wild population in Kejimkujik National Park, Nova Scotia. Analyses include first day travel only. Nests with mean vector length (r) > 0.6 are considered to have directed movement; nests with (r) > 0.6 and having a mean vector angle (ω) $\leq 25^{\circ}$ of water nearest the nest are considered to have directed movement toward water. Although 42 hatchlings were trailed in 1994, only 41 trails were suitable for analysis; similarly, while 36 hatchlings were trailed in 1995, only 28 trails were suitable for analysis.

1994				1995			
Nest	Hatchlings trailed	Distance (m) / orientation (^{O}) to nearest water	Length (r) / angle (ω) of mean vector	Nest	Hatchlings trailed	Distance (m)/ orientation (^{O}) to nearest water	Length(r)/ angle (ω) of mean vector
1[a]	8	4.80 / 84	0.30 / 280	1[a]	3	34.95 / 172	0.38 / 141
2[b]	8	~150.00/ 289	0.90 / 356	2[a]	7	11.40 / 276	0.18 / 191
7[a]	5	7.10 / 230	0.18 / 180	6	1	10.05 / 222	— / 009
8[b]	5	14.80 / 240	0.82 / 317	7[a]	2	~150.00 / 289	0.39 / 057
9[c]	2	6.20 / 230	0.89 / 253	10[c]	2	11.00 / 101	0.76 / 098
10[a]	7	8.50 / 225	0.35 / 114	11[a]	9	16.01 / 187	0.33 / 273
13[a]	6	15.20 /180	0.35 / 190	12[c]	4	15.60 / 228	0.67 / 214

a: no directed movement b: directed movement; not toward water. c: directed movement toward nearest water.

Directed defined as $r > 0.06$ and mean vector angle (ω) within 25^{O} of nearest water.

Table 7. Range (λ) as a measure of dispersion in daily travel orientation (ψ'') of individual hatchling Blanding's turtles in Nova Scotia. Individuals are considered to have followed a consistent bearing among days when $\lambda \leq 22.5^{\circ}$.

Hatchling	Range (λ) day 1 to 2 of travel	Range (λ) over all of travel	No. days traveling (n>2) *	Hatchling	Range (λ) day 1 to 2 of travel	Range (λ) over all of travel	No. days traveling (n>2) *
1B94	42.7	---	---				
1C94	61.8	---	---	2A95	1.2 B	5.8	4 *
1D94	171.8	---	---	2B95	31.8	35.6	3
1E94	173.4	---	---	2C95	85.6	136.2	4
1F94	2.7 b	---	---	2D95	1.2 b	---	---
1G94	8.3 b	---	---	2E95	140.5	---	---
				2G95	104.8	289.3	4 *
2A94	99.8	---	---*	2H95	110.7	233.0	4
2B94	27.4	78.1	3				
2C94	170.1	---	---	6A95	152.3	182.4	3
2D94	163.1	---	---				
2E94	99.6	193.2	3	11A95	8.5 b	---	---
2F94	179.6	---	---	11C95	4.8 b	---	---
2G94	93.2	180.4	3	11D95	61.4	---	---
2H94	90.0	---	---	11G95	101.6	---	---*
8A94	115.2	---	---				

*The number of days of travel is not necessarily the number of days after release since some individuals remained stationary for at least one full day. For example, hatchling 2A95 only moved on 4/11 days it was observed.

b Consistent bearing ($\lambda<22.5^{o}$) in first two days; B Consistent bearing ($\lambda<22.5^{o}$) overall.

Table 8. Thermal properties of nests and non-nests. Student t-test was performed on the differences within pairs (A-B)

Code*	Site	Nest	Start record	Stop record	Interval mins.	Cumulative Heat Units	A - B
A	Atk1	1(95)	8/6/95 0:14	9/16/95 0:13	36	329.671	5.119
B	Atk1	1(95)	8/6/95 0:06	9/16/95 0:06	36	324.552	
A	GI	6(95)	7/17/95 0:03	8/18/95 0:03	36	304.994	3.639
B	GI	6(95)	7/17/95 0:32	8/18/95 0:32	36	301.355	
A	GI	9(95)	7/18/95 0:18	8/19/95 0:18	36	294.545	-11.090
B	GI	9(95)	7/18/95 0:32	8/19/95 0:32	36	305.635	
A	Atk1	11(95)	8/6/95 0:23	9/16/95 0:23	36	333.294	18.083
B	Atk1	11(95)	8/6/95 0:15	9/16/95 0:15	36	315.211	
A	Atk1	12(95)	8/6/95 0:33	9/16/95 0:33	36	333.667	74.997
B	Atk1	12(95)	8/6/95 0:21	9/16/95 0:21	36	258.670	
A	GI	15(95)	8/20/95 0:20	9/16/95 0:20	36	177.971	11.801
B	GI	15(95)	8/20/95 0:02	9/16/95 0:02	36	166.170	
A	GI	16(95)	7/18/95 0:23	8/19/95 0:23	36	309.106	-2.410
B	GI	16(95)	7/18/95 0:29	8/19/95 0:29	36	311.516	
A	GI	1(96)	7/30/96 0:04	8/21/96 0:04	24	169.018	excluded **
B	GI	1(96)	7/30/96 0:19	8/21/96 0:19	24	171.909	
A	GI	3(96)	7/30/96 0:15	8/21/96 0:15	24	219.343	33.849
B	GI	3(96)	7/30/96 0:12	8/21/96 0:12	24	185.494	
A	GI	7(96)	7/30/96 0:22	8/21/96 0:22	24	210.835	-31.413
B	GI	7(96)	7/30/96 0:02	8/21/96 0:02	24	242.248	
A	HM2	9(96)	7/10/96 0:32	7/30/96 0:32	24	152.321	21.551
B	HM2	9(96)	7/10/96 0:17	7/30/96 0:17	24	130.770	
A	GI	15(96)	7/30/96 0:09	8/21/96 14:09	24	219.867	30.538
B	GI	15(96)	7/30/96 0:08	8/21/96 14:08	24	189.329	
A	HM2	16(96)	7/10/96 0:09	7/30/96 0:09	24	142.852	15.951
B	HM2	16(96)	7/10/96 0:14	7/30/96 0:14	24	126.901	
A	HM2	17(96)	7/31/96 0:03	8/29/96 0:03	24	239.423	-19.264
B	HM2	17(96)	7/31/96 0:19	8/29/96 0:19	24	258.687	

Ho: $\mu \leq 0$ if $t \geq t_{\alpha(1),v}$ then reject Ho
n 13 mean 11.642
v 12
s2 721 Sx 7.447
t 1.563
P (t ≥ 1.356) 0.10

*A: nest site * B: non- nest pair

** excluded from calculation because a Blanding's turtle nested beside the non-nest pair in what was thought to be the section avoided by nesting turtles.

Table 9. Nesting ecology records from 6 populations of Blanding's turtle.

Population	Michigan	Massachusetts	Ontario	Wisconsin	Illinois	Nova Scotia
Source	a, b	c, d	e , f	g, h	i	j, k, l
Adult female body size mean plastron length	184.5 mm b	—	164.7 f	172 h	—	198.5 l
Age at maturity (yrs)	14 - 20 m	13 - 15 d	14.1 -14.2 e	18 h	—	>13, ca. 19 l
Nesting season	May - June a,b	12 - 17 June c	mid June to early July f	—	26 May - 22 June	June - July
Proportion of fem. pop. reproducing/ year	23% - 48% b	—	—	—	—	33% 22 / 66 (l/j)
Nest -water (mean) distance (m)	135 b 2 - 1115 b	100 - 200 c	inland e border water f	168 g	815 ω inland	< 10 j,k,l mostly beach
Nesting substrates	—	sand - loam c	sand e, f gravel e, γ	sandy loam g sand g	—	pebbles/cobble

Table 9. Nesting ecology records from 6 populations of Blanding's turtle (cont).

Population	Michigan	Massachusetts	Ontario	Wisconsin	Illinois	Nova Scotia
Mean clutch size	8.3 a - 10 b	10.6 c	7.6 - 12.6 e 8.0 f	---	---	10.3 l
Predation rate	42% - 93% b	94% c	17%	75% - 100%	---	---
Nest failure due to causes other than predation	33% 8/24 b	7% 1/14 c	---	---	---	26% k, l 6.6% - 50% l
Total egg failure * - no predation (n eggs) (unhatched + dead embryos)	---	13% c 149	---	---	---	38% ψ, υ l 488 (see Table 5)

Table 9. Nesting ecology records from 6 populations of Blanding's turtle (cont).

Population	Michigan	Massachusetts	Ontario	Wisconsin	Illinois	Nova Scotia
Productive nests **min. 1 live hatchling**	67% 16/24 b	92% 13/14 c	---	---	---	74% k,l 50% - 93%
Nests 100% hatch	43% 7/16 b	---	---	---	---	13% k, l 7% - 22%
Non viable eggs */ **productive nest**	1 β, b 1.2 b	---	---	---	---	1.8 ψ, l
Incubation (days) ϕ						
mean	84 b	76.8 c	---	---	---	93.4 l
range	73 - 104 b	66 - 90 c				82 - 121
Hatchling emergence	mid Aug. to early Oct. b	18 Aug. to Sept. c	---	---	---	6 Sept - 25 Oct.

a Gibbons 1968
b Congdon et al. 1983
c Butler and Graham 1995
d Graham and Doyle 1977
e Petokas 1986
f MacCulloch et al. 1988
g Ross and Anderson 1990
h Ross 1989
i Rowe and Moll 1991
j Herman et al. 1995
k Power 1989
l This study
m Congdon an van Loben Sels 1993

ψ This is likely an underestimate because emergence was very late, and numerous hatchlings died shortly after emergence.

ϕ Oviposition to 1st emergence

α One productive nest excluded because excavation data were not available.

λ Recalculation from Power 1989:
unhatched eggs + hatchlings dead at excavation/ productive nest.

β Recalculation from Congdon et al. 1983: 16 productive nests were reported.
I have excluded 3 productive nests from the calculations
since these were predated after first emergence. These are analogous
to productive nest (1994) for which excavation data were unavailable.
= (unhatched eggs + dead embryos) / productive nest

ϖ Unhatched eggs (only)/productive nest

ω Distance from female's home pond. From text turtles appear to nest inland.

γ Assume 'gravel' is used generically pebbles to large boulders comprise this size class.

* Unhatched eggs + excavate dead hatchlings

** (77 unhatched eggs + 1 excavated dead hatchling)/estimated clutch size

Table 10. Historical records of incubation intervals for Blanding's turtle eggs in natural nests in Kejimkujik National Park. Incubation time was determined once per nest; it is the interval in days between oviposition and the natural (unaided) emergence of the first hatchling from the nest.

Incubation time (days) (O-E_1)	No. nests	First emergence	Last live excavation	Year	Source
88	1	Sept. 27	---	1959	Bleakney 1963.
89	1	---	---	1971-72	Weller 1971-72 a.
98	1	Sept. 30	Oct. 19	1977	Thexton Mallet 1977 - 79.
---	1	Sept. 25	---	1981	Drysdale 1983.
104	1	Oct. 1	Oct. 20	1987	Power 1989.
85 - 105	8	Sept. 11	Nov. 4	1988	Power 1989.
> 118 b	5	---	Oct. 21	1992	Morrison 1992.
83c - 104	8	Sept. 11	Oct. 4	1993	Morrison 1993.
83 - 121	11	Sept. 6	Oct. 17	1994	This study.
82 - 106	12	Sept. 11	Oct. 6 d	1995	This study.
107	2	Oct. 2	Oct. 16	1996	This study.

a as cited in Power 1989; b In Morrison 1992, no emergence had occured by Oct. 20 (day 118) so nests were excavated and incubated indoors; c Discrepency in data reported so minimum incubation time may have been 83 or 85 days; d This is the last day on which live hatchlings were excavated from nests, however, the last natural emergence occured on October 25, 1995, and is the latest recorded natural emergence of hatchling Blanding's turtles in this population.

Figure 1. Updated Blanding's turtle (*Emydoidea blandingii*) distribution map; reproduced with permission from Herman *et al.* (submitted). Most historical records are after McCoy (1973) (closed symbols). Circles represent extant populations, and stars and triangles represent fossil and archeaological finds. Numbers for citations of updated information: 1 Maine (Graham *et al.* 1987, Graham and Doyle 1973); 2 Massachusetts (Graham 1986); 3 New York (Petokas and Alexander 1981, 1978); 4 Ontario (Weller and Oldham 1988, Petokas and Alexander 1980); 5 Wisconsin (Cochran and Lyons 1986); 6 Minnesota (Olson 1987, Ernst 1973); 7 Mississippi (Jackson and Kaye 1974); 8 Nebraska (Hutchison 1981). Archeological records have been found in western Missouri (not marked) (vanDevender and King 1975) 9 Maine (Speiss and Sobolik 1997, French 1986) and 10 Ontario (Bleakney 1958b). Most reports of this species in Quebec are from Parc de la Gatineau and surrounding area and in La Rivière du Nord between Carillon and Lachute (Matte 1989, Cimon 1986, McMurray 1984, Melançon 1950). The species has been extirpated from Rhode Island (Herman *et al.* submitted) and from Connecticut (Klemens 1993). The most recent range extension was a report from Wayne Co., Indiana (Iverson 1996). Recent efforts in Nova Scotia have located previously unidentified concentrations of Blanding's turtle outside Kejimkujik National Park, but the population's range still appears centred in the southwestern interior (Herman, pers. comm.).

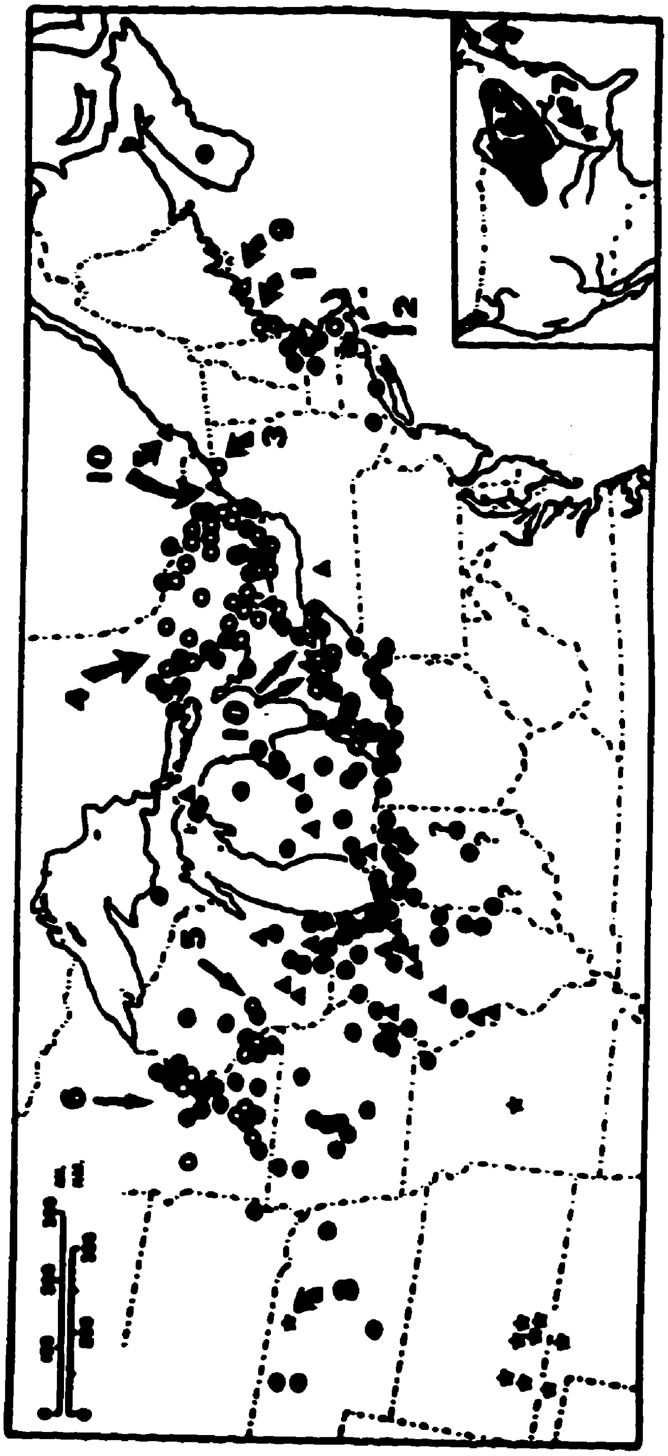

9
1
2
3
10
4
10
5
6

Figure 2. Blanding's turtle nesting frequencies for three consecutive years in Kejimkujik National Park, Nova Scotia. Each point (closed circles, closed triangles, and open diamonds) represents one protected nest. The open triangle represents a nest discovered shortly after oviposition, but the female was not observed nesting. The open circle represents a nest discovered after predation. The asterix and cross represent sightings of individual females engaged in nesting activities, although no nests were located.

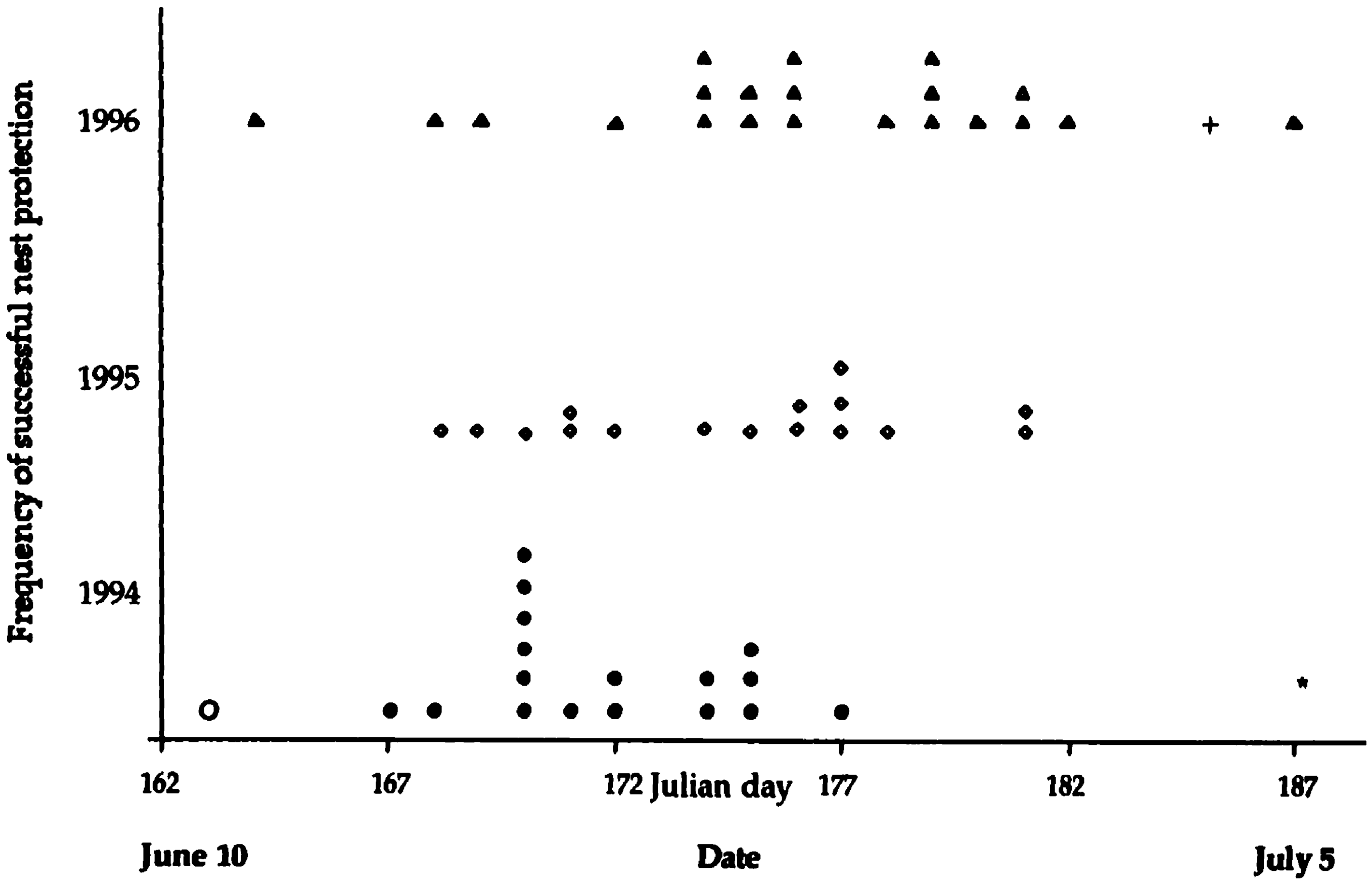
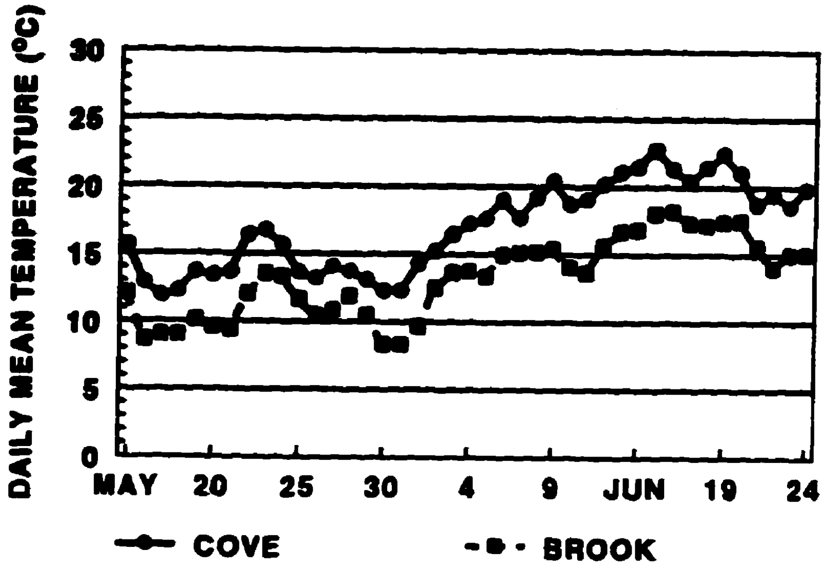
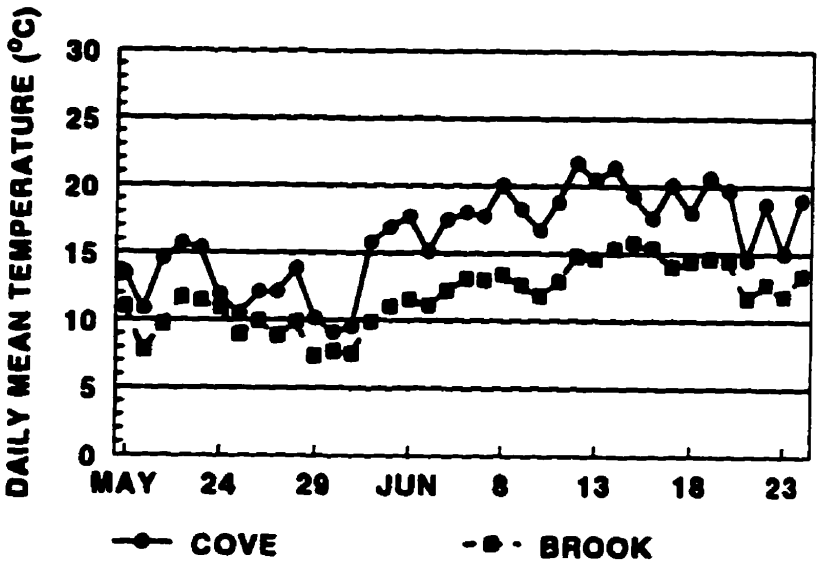

Frequency of successful nest protection
1996
1995
1994
162
167
172 Julian day
177
182
187
June 10
Date
July 5

Figure 3a. Water temperature measured in the sheltered cove behind Atkin's beach, and in nearby Atkin's brook. Temperature was recorded at 10 cm depth at regular intervals with an automated thermistor.

Figure 3b. Water temperature measured in the sheltered cove adjacent to Heber Meadow beach, and Heber Meadow brook. Temperature was recorded at 10 cm depth at regular intervals with an automated thermistor.


DAILY MEAN TEMPERATURE (°C)
30
25
20
15
10
5
0
MAY
20
25
30
4
9
JUN
19
24
COVE
BROOK

A


DAILY MEAN TEMPERATURE (°C)
30
25
20
15
10
5
0
MAY
24
29
JUN
8
13
18
23
COVE
BROOK

B

Figure 3c. Water temperature measured in the sheltered cove behind Peter Point (II) beach, and in the lake adjacent the nesting beach. Temperature was recorded at 10 cm depth at regular intervals with an automated thermistor. Although the water is not warmer in the cove, the exposed log is often used for basking and could make the site more attractive to gravid turtles. The female Blanding's turtles observed in this cove arrived a few days before oviposition, and returned to their summer home range shortly thereafter.

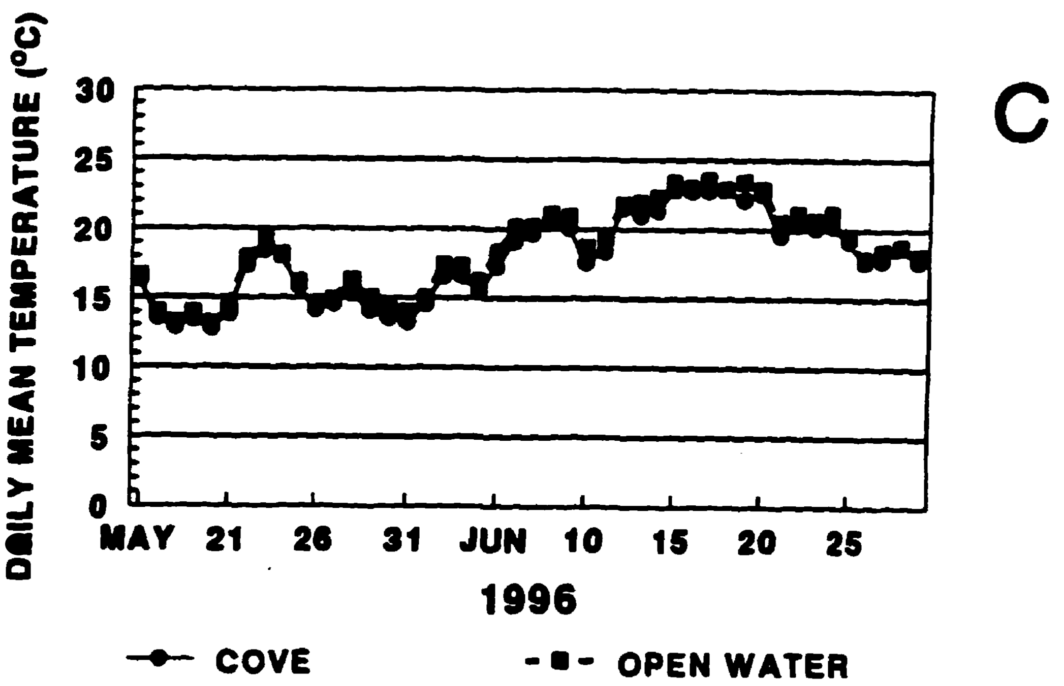

C
DAILY MEAN TEMPERATURE (°C)
30
25
20
15
10
5
0
MAY
21
26
31
JUN
10
15
20
25
1996
COVE
OPEN WATER

Figure 4. Frequency distribution of nest slopes (degrees) for 31 Blanding's turtle nests constructed in Kejimkujik National Park, Nova Scotia between 1994 and 1996.

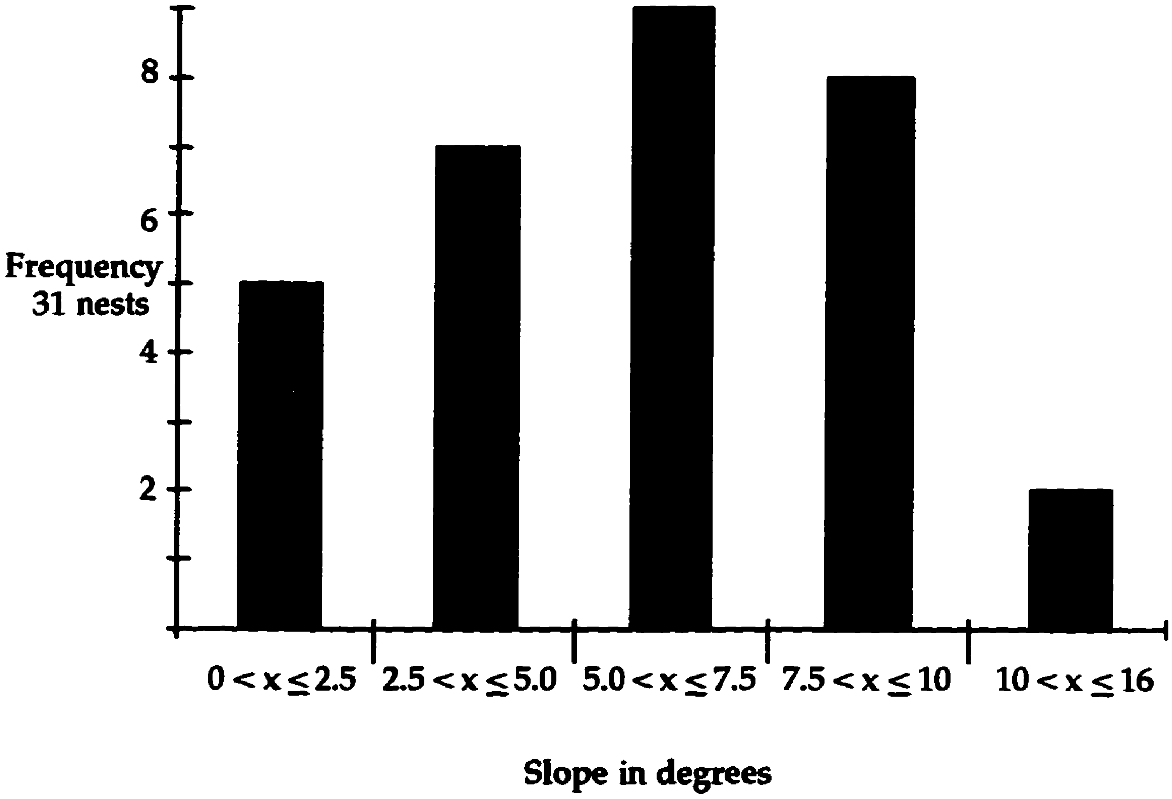

8
6
4
2
Frequency
31 nests
0 < x ≤ 2.5
2.5 < x ≤ 5.0
5.0 < x ≤ 7.5
7.5 < x ≤ 10
10 < x ≤ 16
Slope in degrees

Figure 5. Aspect of Blanding's turtle nests in Kejimkujik National Park, Nova Scotia. The non-random distribution (Rayleigh test) shows that females use southwestern aspects significantly more often than slopes facing in other directions (Magnetic North).

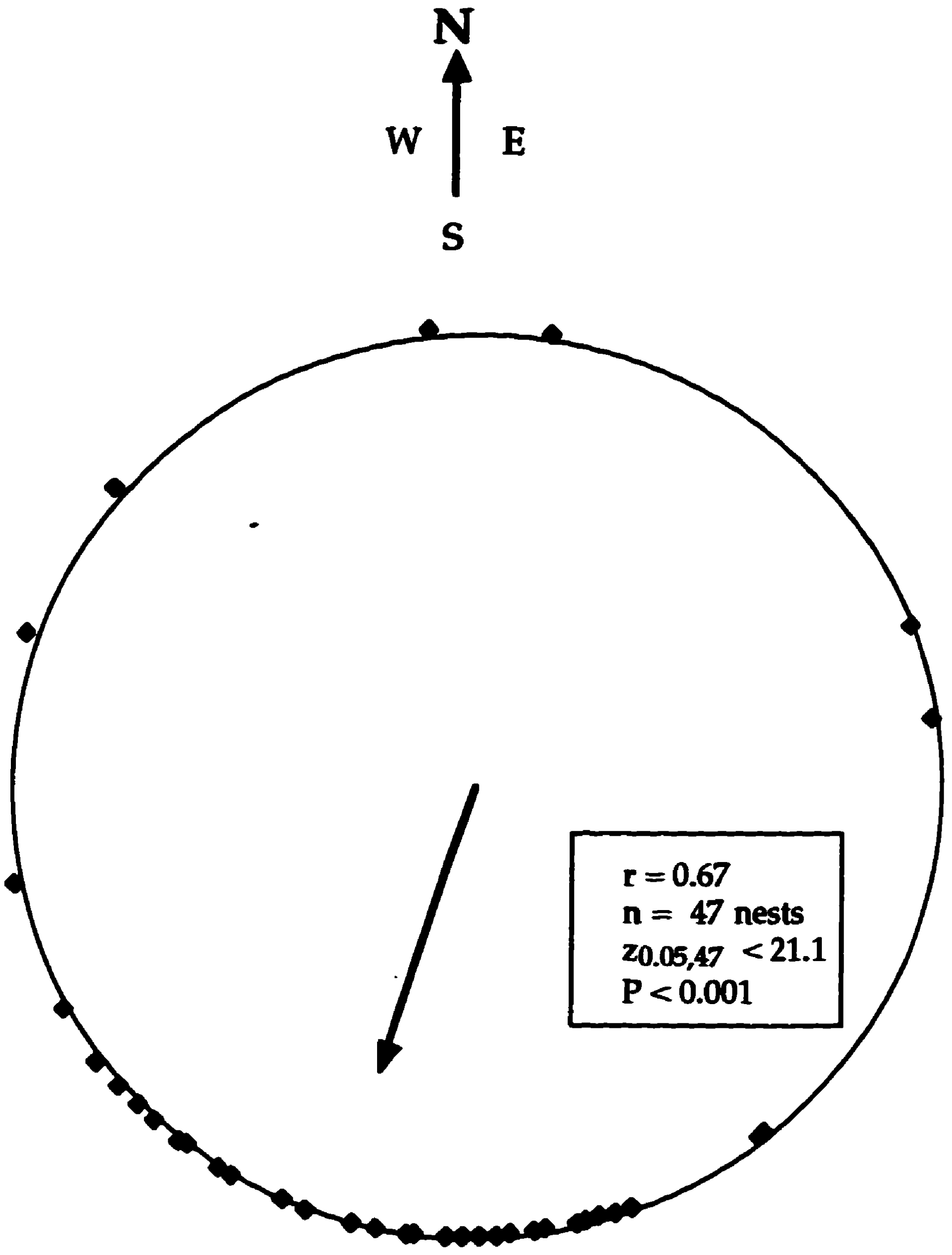

N
W
E
S
r = 0.67
n = 47 nests
$z_{0.05,47}$ < 21.1
P < 0.001

Figure 6. The range of grain sizes (% of individual sample weight) of 16 Blanding's turtle nests in Nova Scotia. Data are from sieving analyses and illustrate the variety of substrates used by this population.

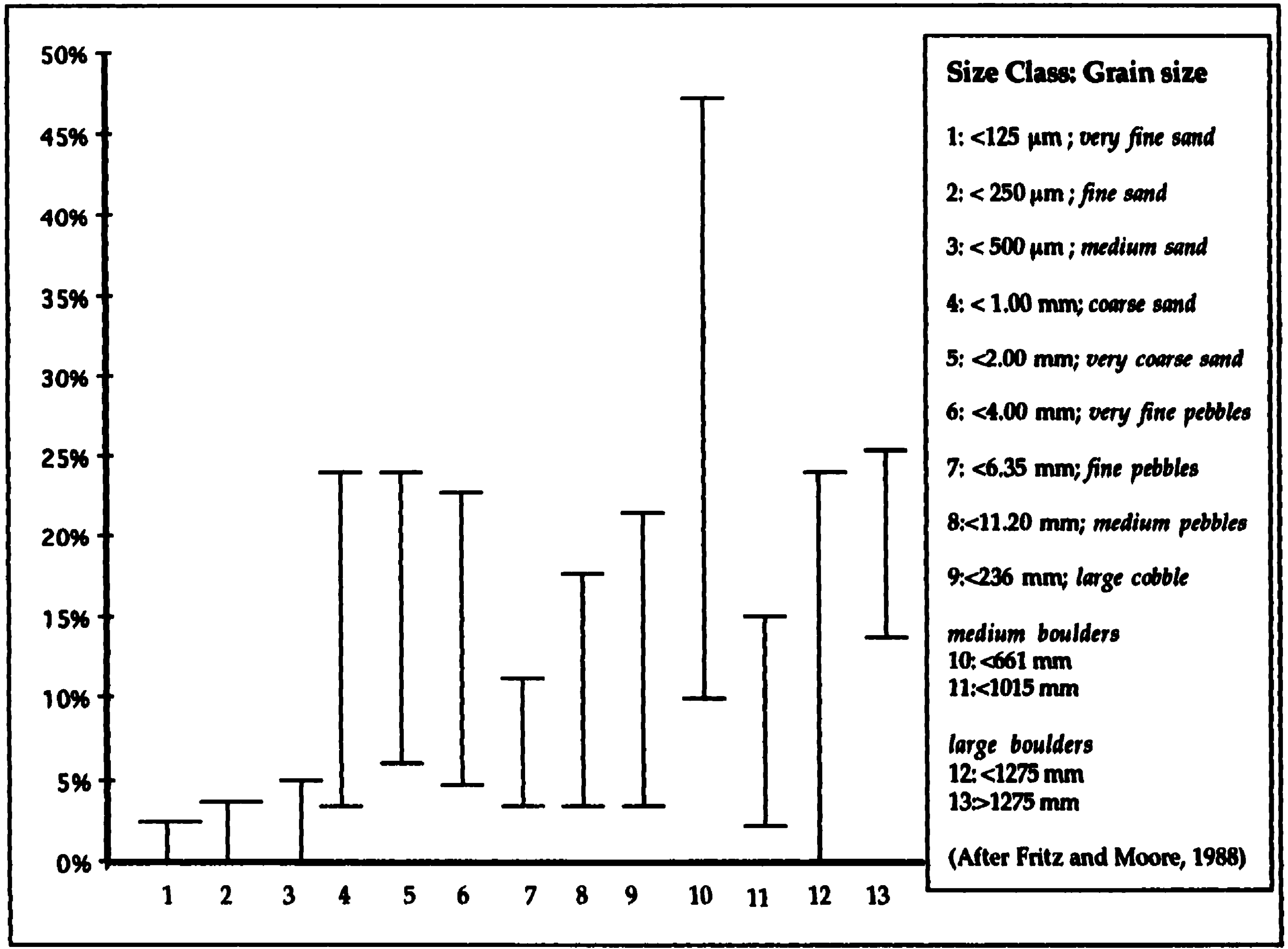

50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
1
2
3
4
5
6
7
8
9
10
11
12
13
Size Class: Grain size
1: <125 µm ; *very fine sand*
2: < 250 µm ; *fine sand*
3: < 500 µm ; *medium sand*
4: < 1.00 mm; *coarse sand*
5: <2.00 mm; *very coarse sand*
6: <4.00 mm; *very fine pebbles*
7: <6.35 mm; *fine pebbles*
8:<11.20 mm; *medium pebbles*
9:<236 mm; *large cobble*
medium boulders
10: <661 mm
11:<1015 mm
large boulders
12: <1275 mm
13:>1275 mm
(After Fritz and Moore, 1988)

Figure 7a. Relationship between age estimates and body size (weight) in sexually immature Blanding's turtles (*Emydoidea blandingii*) in Nova Scotia, Canada. Data adapted from McMaster (1996) (open circles) and this study (closed circles). Age was estimated by counting the growth rings visible on the scutes; it is assumed that a single annulus is deposited per year in young turtles. Age estimates are considered conservative and may underestimate age. Congdon and van Loben Sels (1991) reported that juvenile Blanding's turtles in Michigan (ages 4 - 13) increased an average of 75.3 g per year, and that between 16 and 18 years, approached a plateau of 1200 g (broken line). Although hatchlings are of similar size in Nova Scotia and Michigan, juvenile growth in Nova Scotia appears relatively slow.

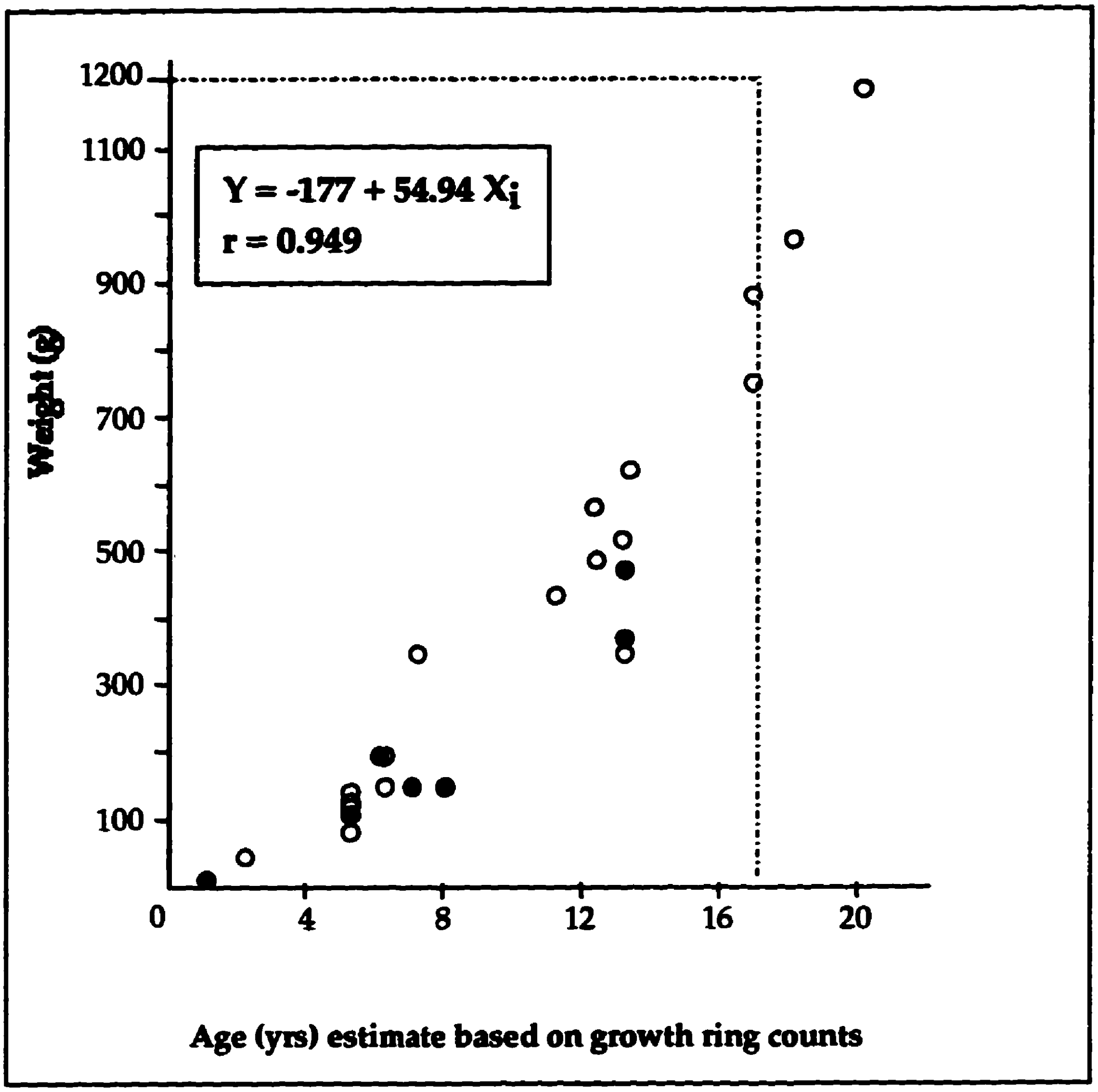

Y = -177 + 54.94 X_i
r = 0.949
Weight (g)
1200
1100
900
700
500
300
100
0
4
8
12
16
20
Age (yrs) estimate based on growth ring counts

Figure 7b. Relationship between age estimates and body size (carapace length (CL)) in sexually immature Blanding's turtles,*Emydoidea blandingii* in Nova Scotia, Canada. Data adapted from McMaster (1996) (open circles) and this study (closed circles). Age was determined by counting the growth rings visible on the scutes; it is assumed that a single annulus is deposited per year in young turtles. Age estimates are considered conservative, and may underestimate age. Congdon and van Loben Sels (1991) reported that juvenile Blanding's turtles in Michigan (ages 1 - 13 years) grew an average of 1.04 cm per year (CL) and that the rate of increase tapered around age 16. In Nova Scotia turtles grow 0.82 cm / year and older turtles (ca. 17 years (1995) showed similar growth rates as younger turtles (ca. 6 years)).

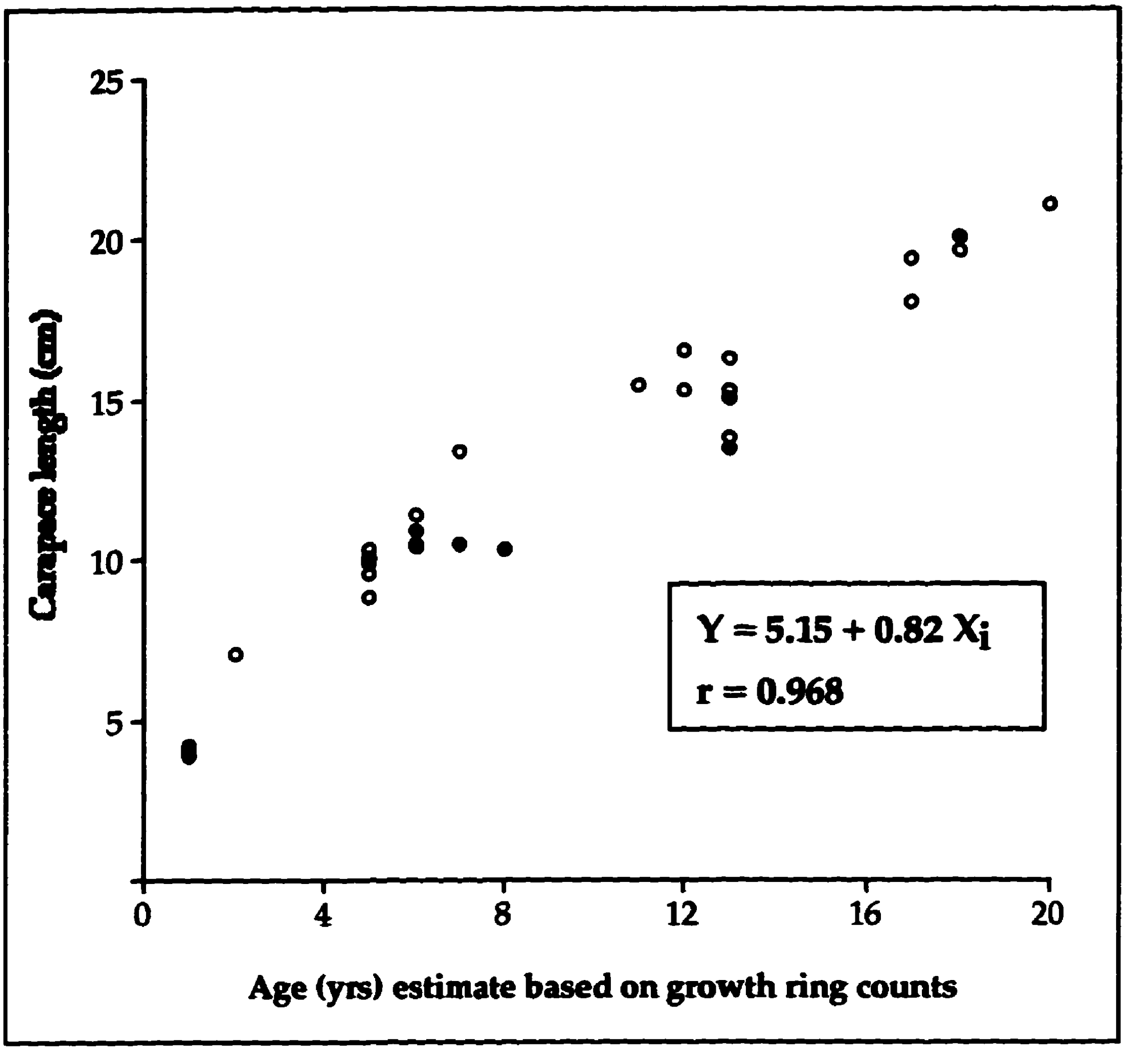
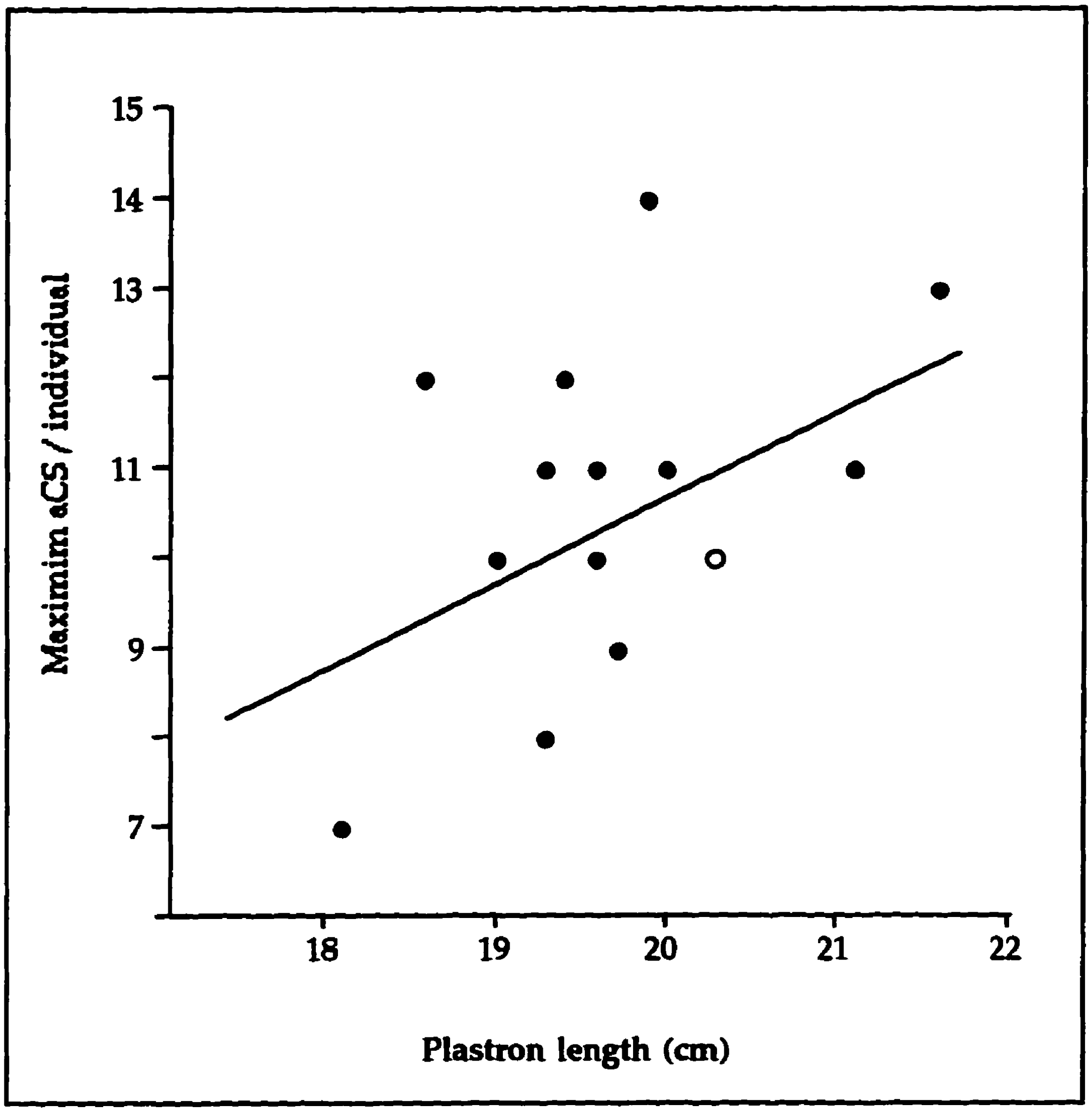

25
20
15
10
5
Carapace length (cm)
0
4
8
12
16
20
Age (yrs) estimate based on growth ring counts
Y = 5.15 + 0.82 Xi
r = 0.968

Figure 8. Body size - clutch size relationship in Blanding's turtles in Nova Scotia. The relationship between adult female body size (PL) and clutch size (maximum absolute clutch size produced by an individual between 1994 and 1996) is not significant ($p < 0.05$) in this population: Correlation coefficient (r) = 0.46; n = 15, line equation: ($Y = -7.7 + 0.92 X$). The open circle represents identical body size measures for two individuals.



15
14
13
11
9
7
Maximim aCS / individual
18
19
20
21
22
Plastron length (cm)

Figure 9a. Early post-emergence trails of two Blanding's turtle neonates from nest 9(94). Nest was located a short distance open from water on the Heber Meadow Beach (I). Between the nest and open water the cobble beach is vegetated with reeds as indicated on map. A short distance northeast of the nest is the upper beach margin which is vegetated with trees and huckleberry. Nestmates were released on the same day and were followed for a single day only. Hatchlings were directed toward nearest water, but neither hatchling actually entered it.

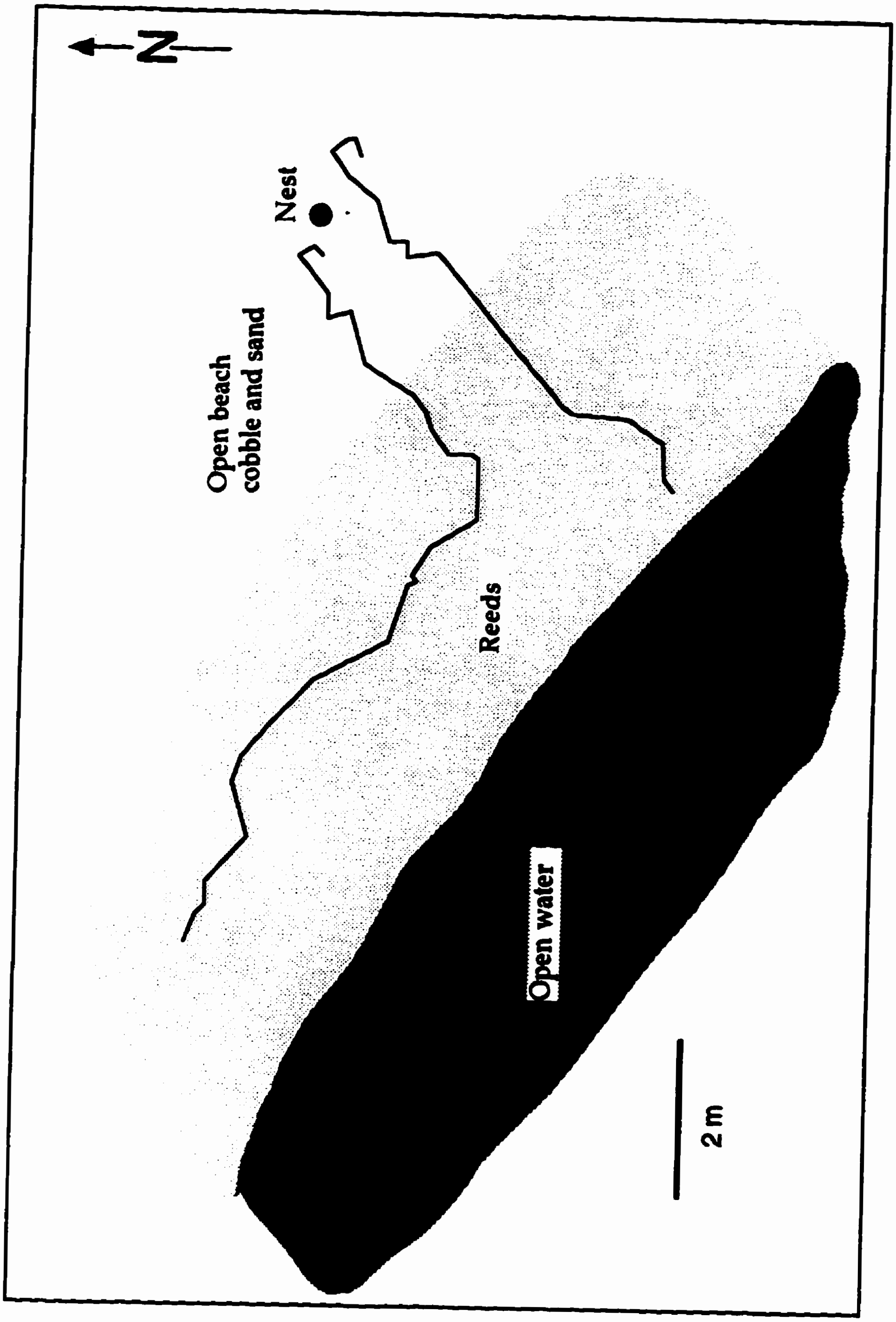

N
Nest
Open beach
cobble and sand
Reeds
Open water
2 m

Figure 9b. Early post-emergence trails of eight Blanding's turtle neonates released from nest 2(94). Nest was located on the gravel shoulder of the one of the Park's main roads, about 150 m southeast of a small roadside marsh. Nestmates were released on the same day and were trailed for a maximum of 4 days. On the first day hatchling movement was directed, although not toward water; instead most hatchlings move down the slope to spend their first night near the vegetated edge (white pine). On subsequent days hatchlings showed no tendency to follow one another, slope, or a fixed compass bearing, nor was there a tendency to seek cover. Hatchlings frequently crossed and walked along the road (broken trails marked with arrows). Hatchlings trailed from a roadside nest in 1995 showed similar patterns, and some even seemed to fall asleep on the road.

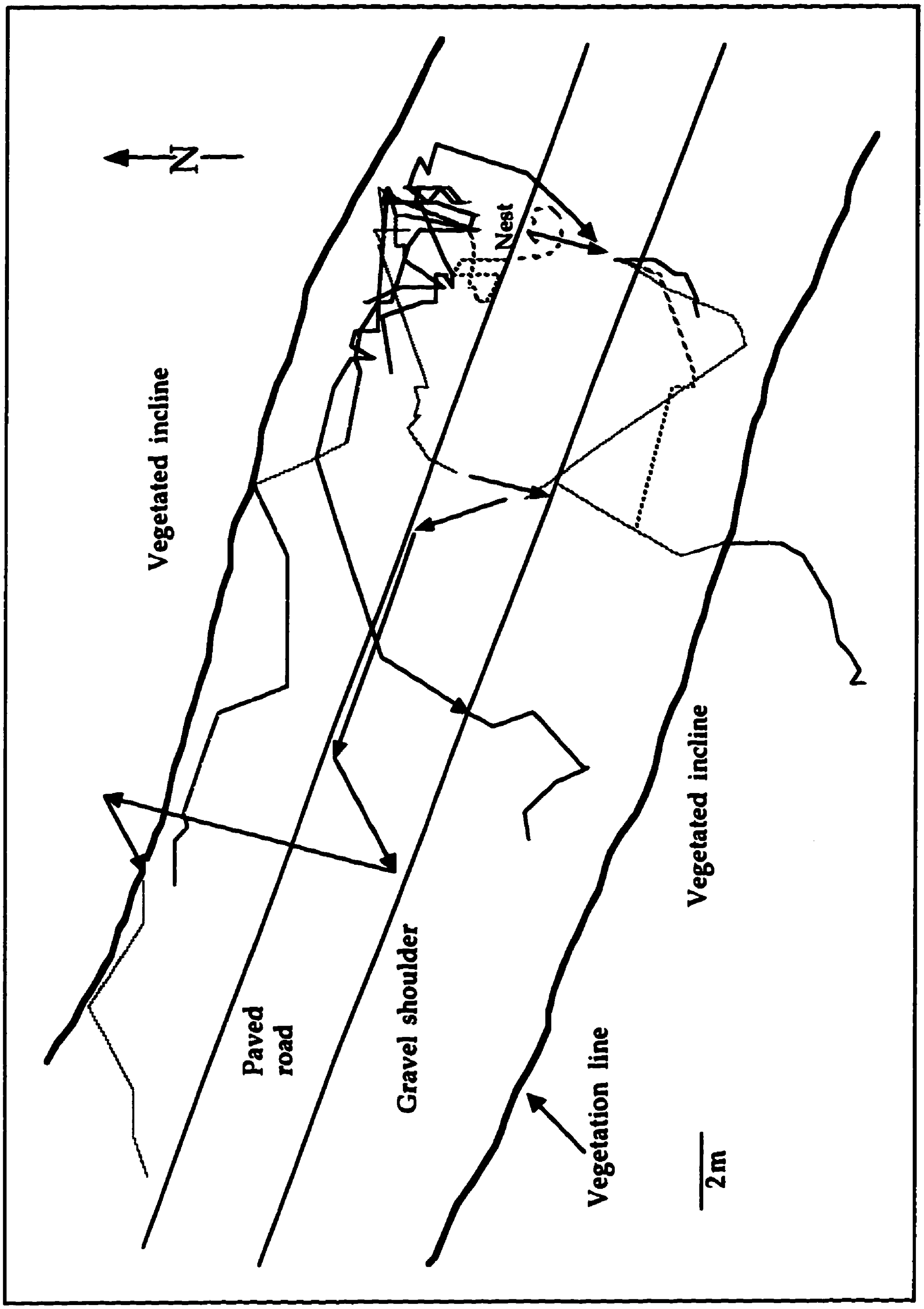

N
Vegetated incline
Nest
Paved road
Gravel shoulder
Vegetation line
Vegetated incline
2m

Figure 9c. Early post-emergence trails of eight Blanding's turtle neonates from nest 1(94). Nest (closed square) was located a short distance open from water on the eastern beach of Glode Island; most Blanding's turtle nesting on the island occurs on the western beach. The cobble beach is sparsely vegetated with patches of cranberry and sweetgale not indicated on map. Nestmates were released on the same day. Open circles represent overnight forms used by hatchlings. Hatchlings showed no propensity to follow one another, topography or a consistent compass bearing within or among days; they did not orient themselves with respect to vegetation, water or any other beach feature, and there is evidence of water avoidance.

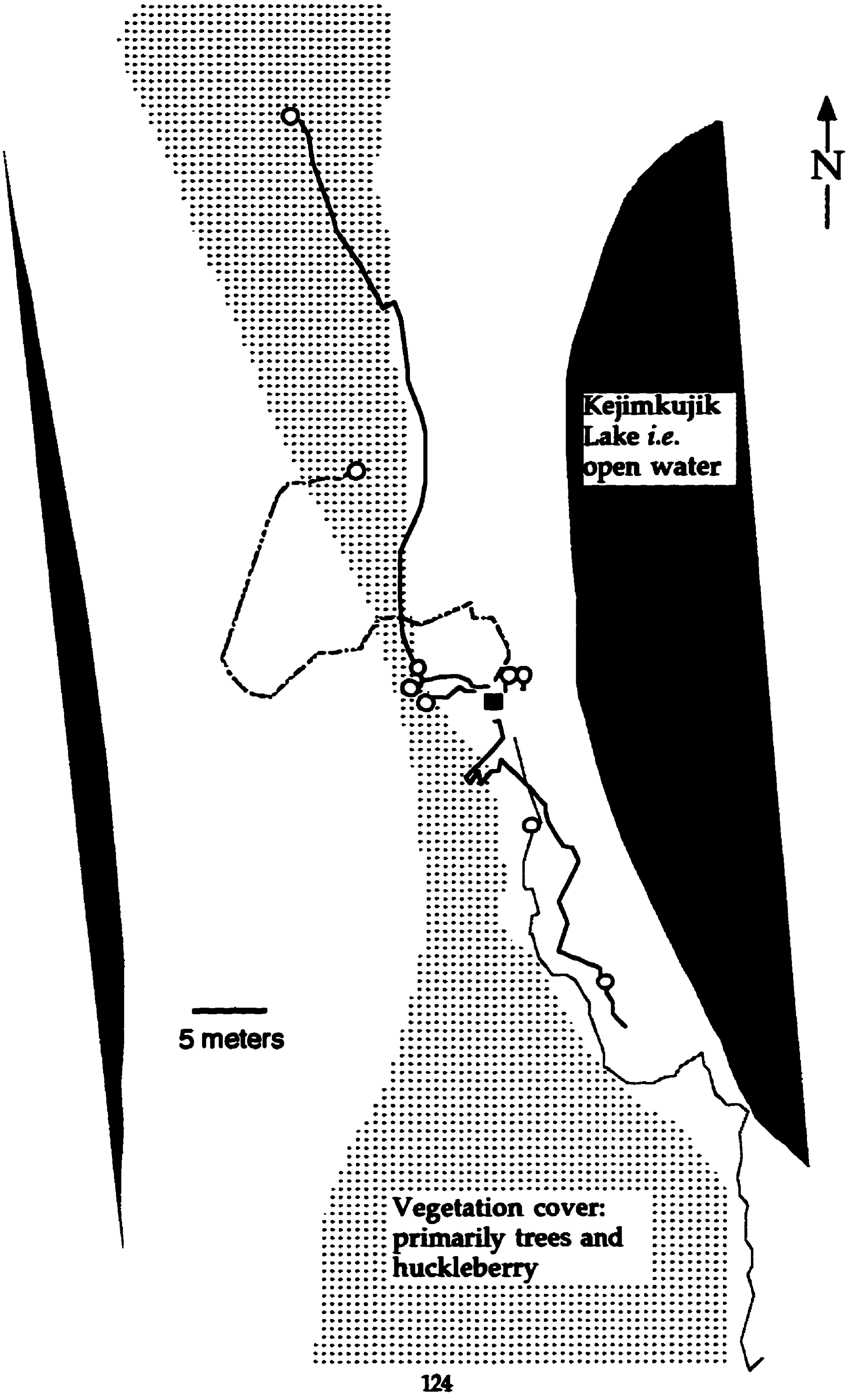

N
Kejimkujik Lake *i.e.* open water
5 meters
Vegetation cover: primarily trees and huckleberry

Figure 9d. Early post-emergence trails of seven Blanding's turtle neonates released from nest 2(95). Hatchlings were trailed for a maximum of 11 days (overnight forms are not marked on map). The nest (closed circle) was located 11.4 m from water on Peter Point beach (II). Hatchling movement on the first day after release was not directed, and water avoidance is obvious in some cases. The shallow cove is the same one used by gravid females during the nesting season (Chapter 1, Figure 3c).

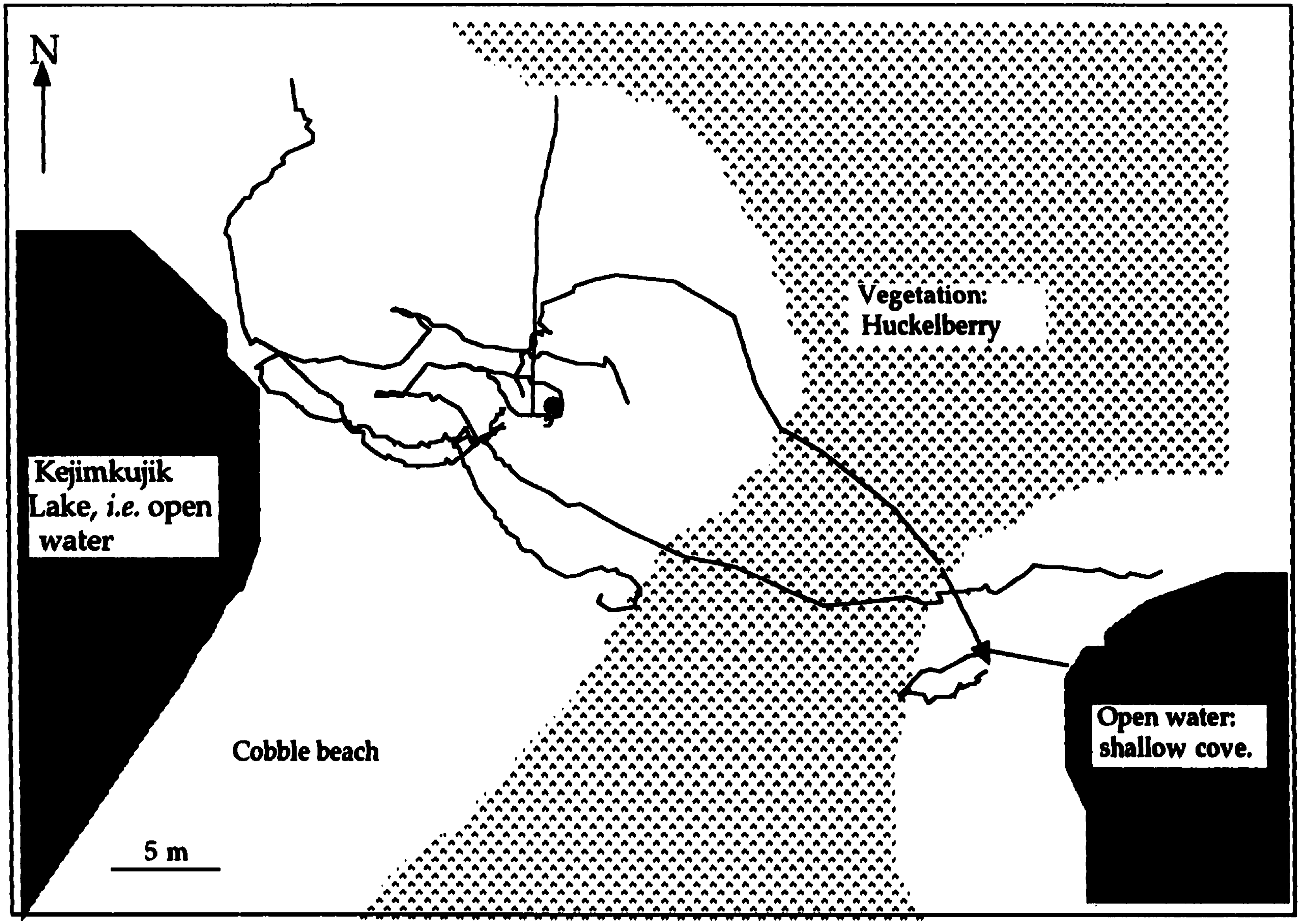

N
Kejimkujik Lake, *i.e.* open water
Vegetation: Huckelberry
Cobble beach
Open water: shallow cove.
5 m

Figure 9e. Early post-emergence trails of six Blanding's turtle neonates released from nest 12(95). The nest (closed square) was located 15.6 m from water on Atkin's beach (I). Four hatchlings exhibited directed movement towards nearest water on the first day. Overall, their trails covered large sections of the beach, and one hatchling from this site reoriented after reaching water and went into the vegetation (trail not shown). One hatchling (open square) remained stationary for several days concealed between cobble.

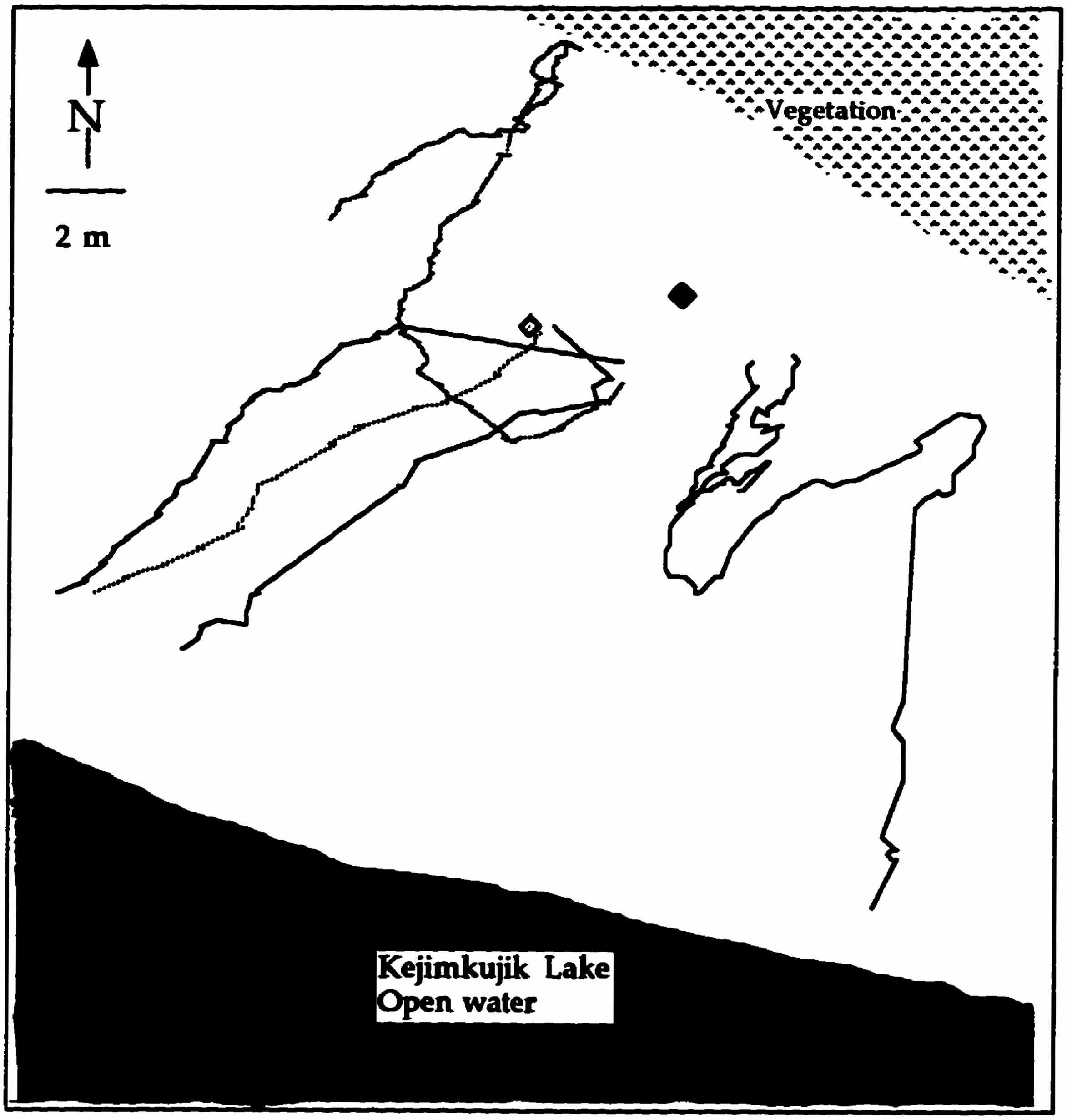

N
2 m
Vegetation
Kejimkujik Lake
Open water

Figure 9f. Early post-emergence trails of seven Blanding's turtle neonates released from nest 10(94). The nest (closed circle) was located on Atkin's beach (I). Hatchlings exhibited no directed movement on the first day (multiple day trails are not distinguishable because locations of overnight forms have not been marked on this map).

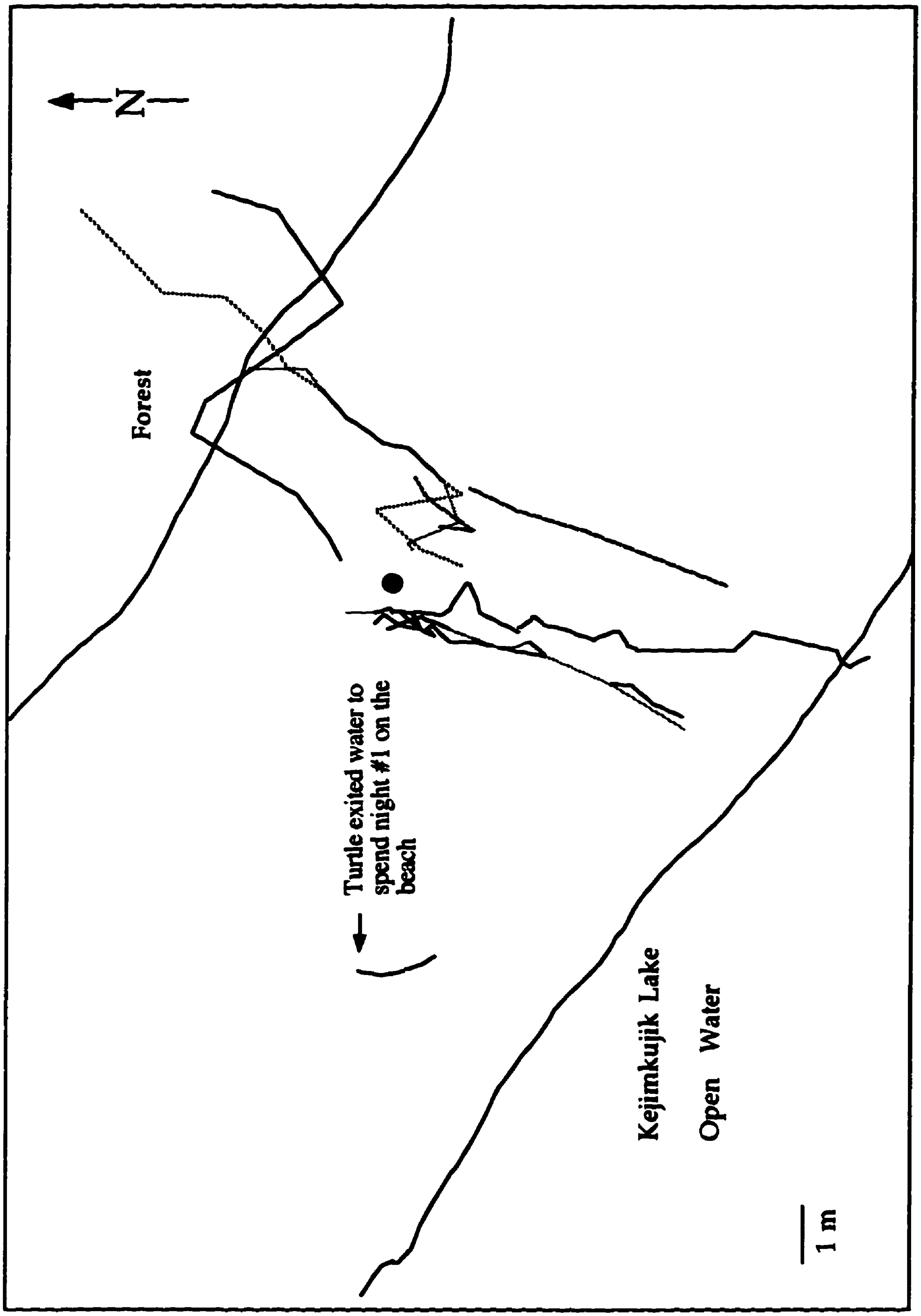

N
Forest
Turtle exited water to spend night #1 on the beach
Kejimkujik Lake
Open Water
1 m

Figure 9g. Early post-emergence trails of two Blanding's turtle neonates released from nest 10(95). The nest (closed circle) was located on Heber Meadow beach (II). Hatchlings exhibited directed movement towards water on the first day, but one hatchling that entered water on the first day, spent its first night exposed on the beach.

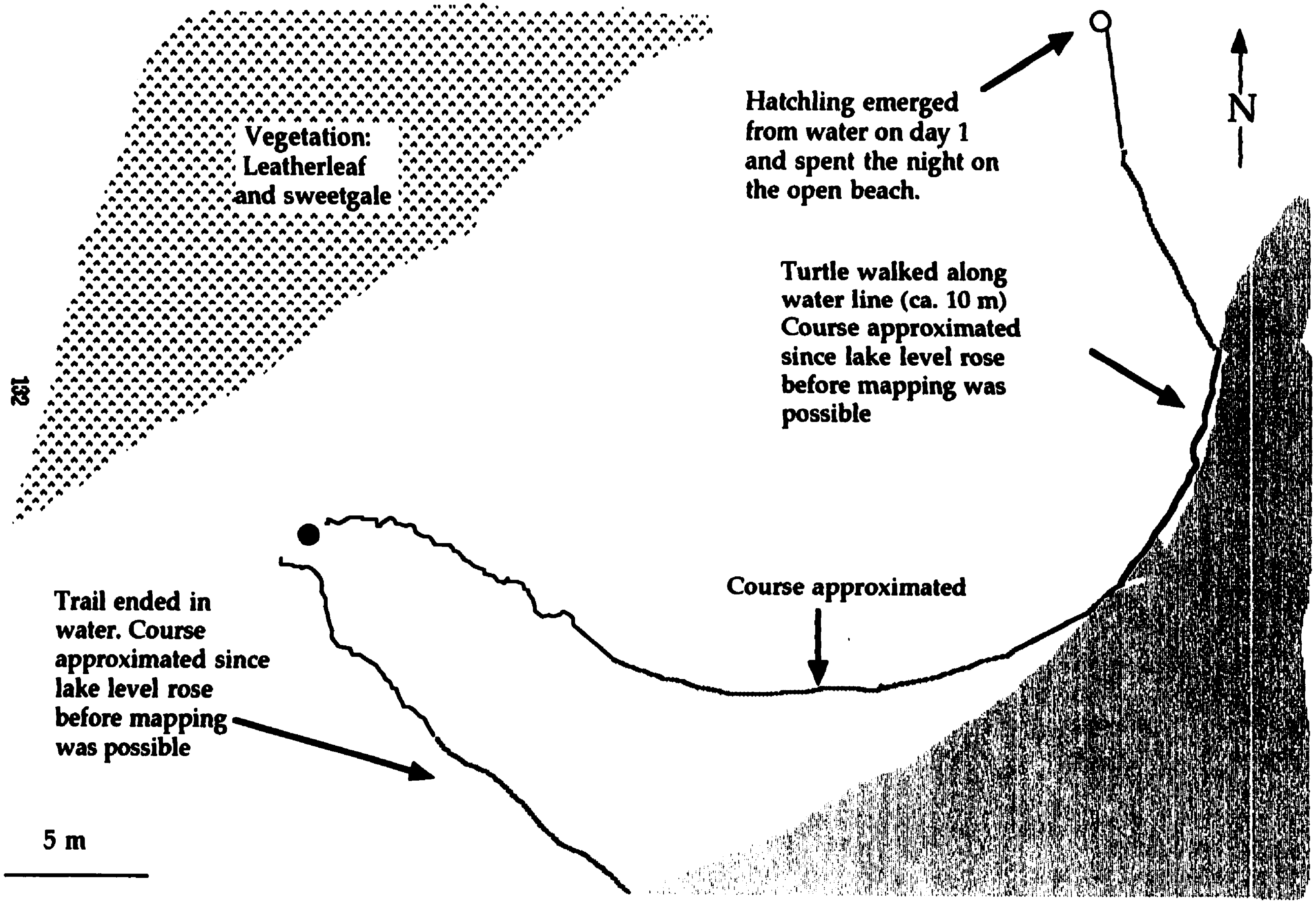

Vegetation: Leatherleaf and sweetgale
Hatchling emerged from water on day 1 and spent the night on the open beach.
N
Turtle walked along water line (ca. 10 m) Course approximated since lake level rose before mapping was possible
Course approximated
Trail ended in water. Course approximated since lake level rose before mapping was possible
5 m

Figure 10a. Movement in relation to nearest water to the nest of 40 Blanding's turtle hatchlings in 1994. Each point on the unit circle represents the angle (ψ) (azimuth from Magnetic North) of the resultant vector (R) of each hatchling's first day trajectory which has been converted to the new polar angle (ψ') (azimuth in relation to water) such that the direction to nearest water is standardized among nests. The arrow is the mean vector (m') of the sample; its length (r') is 0.234 and angle (ϕ') is 64.7° clockwise from water. At significance level $\alpha = 0.05$, the null hypothesis is accepted, that is, initial movement is random with respect to nearest water.

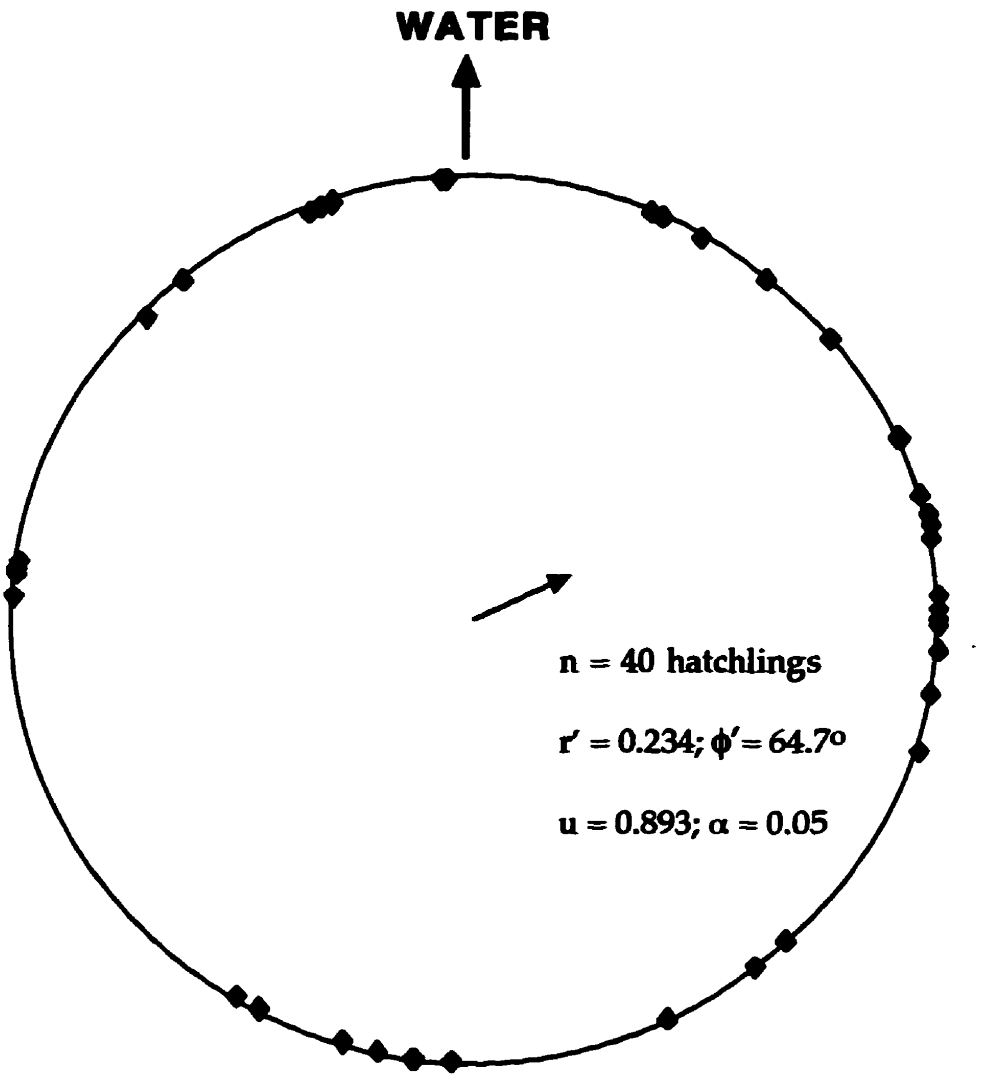

WATER
n = 40 hatchlings
$r' = 0.234; \phi' = 64.7°$
$u = 0.893; \alpha = 0.05$

Figure 10b. Movement in relation to nearest water to the nest of 28 Blanding's turtle hatchlings in 1995. Each point on the unit circle represents the angle (ψ) (azimuth from Magnetic North) of the resultant vector (R) of each hatchling's first day trajectory which has been converted to the new polar angle (ψ') (azimuth in relation to water) such that the direction to nearest water is standardized among nests. The arrow is the mean vector (m') of the sample; its length (r') is 0.168 and angle (ϕ') is 2.5^{o} clockwise from water. At significance level $\alpha = 0.05$, the null hypothesis is accepted, that is, initial movement is random with respect to nearest water.

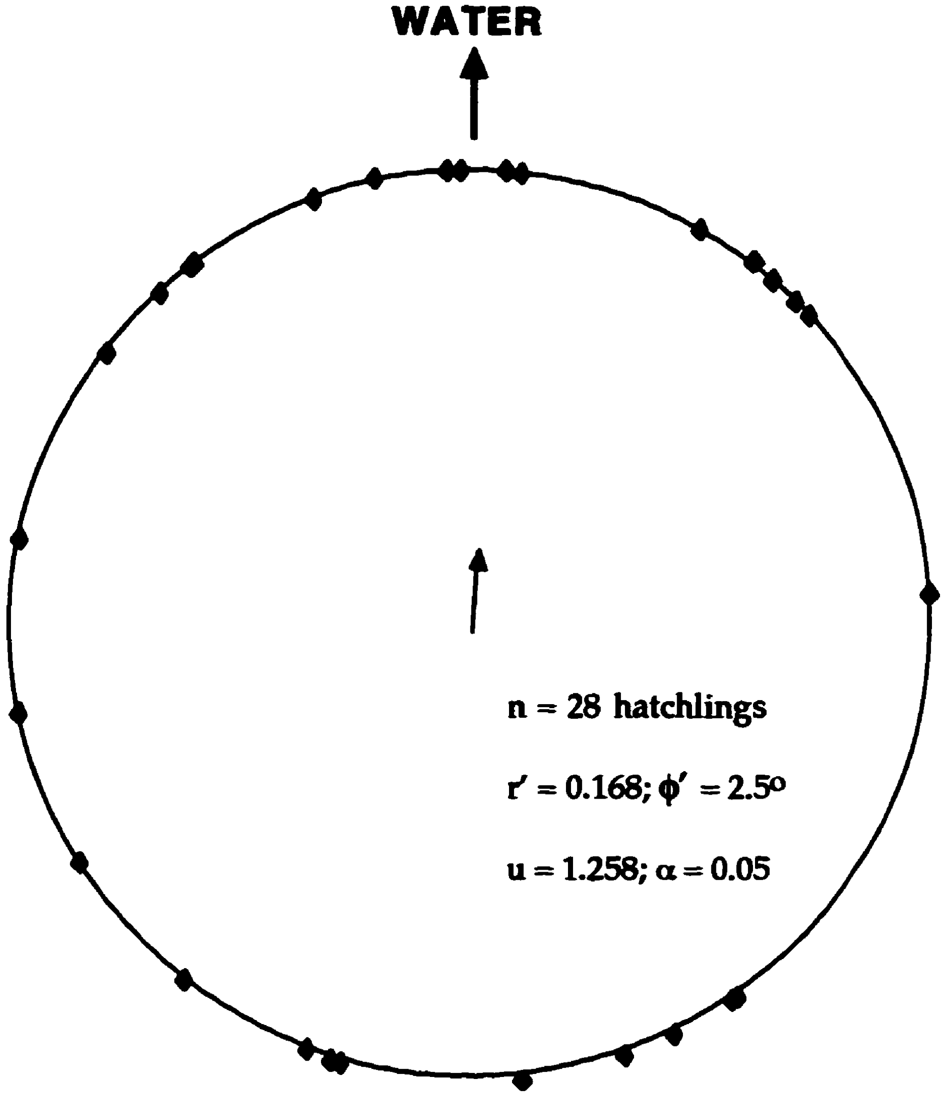
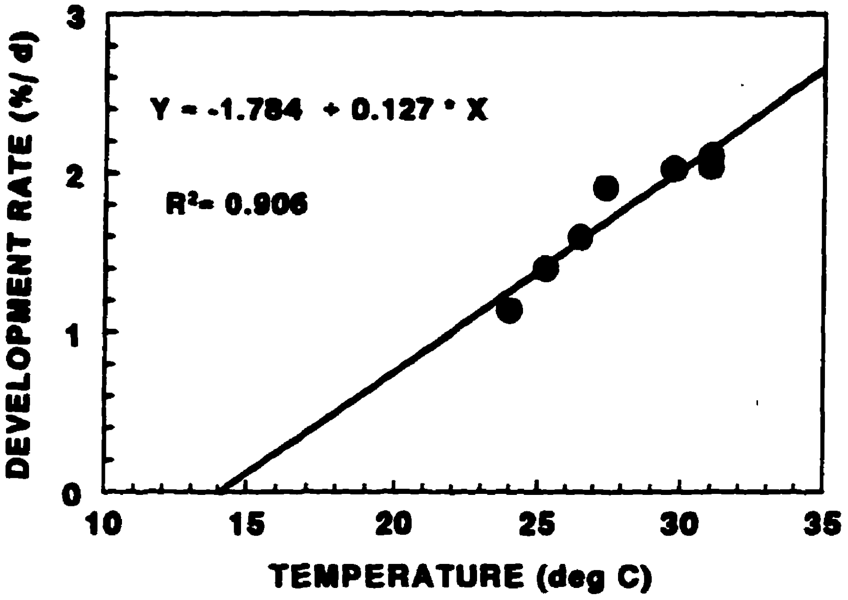
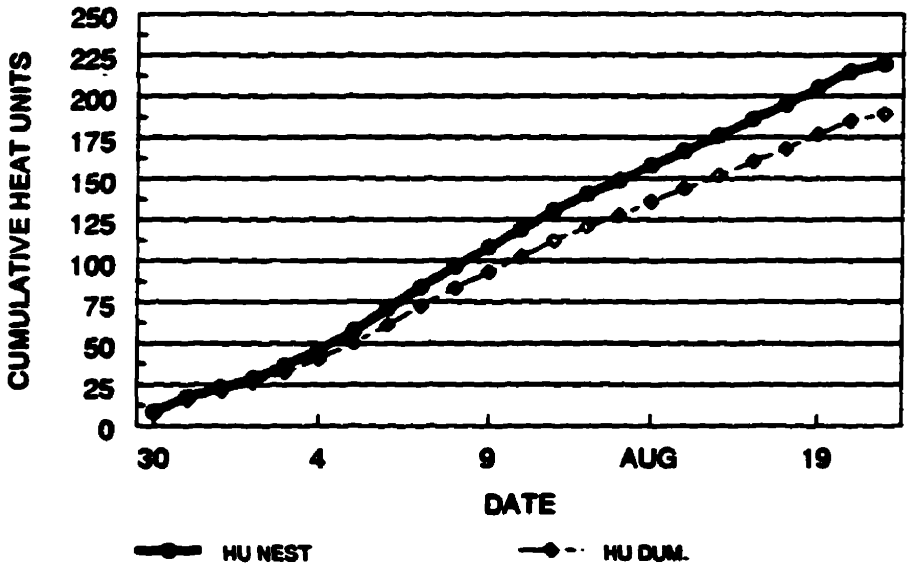

WATER
n = 28 hatchlings
$r' = 0.168$; $\phi' = 2.5^{\circ}$
$u = 1.258$; $\alpha = 0.05$

Figure 11a. Calculation of minimum threshold for development of Blanding's turtle eggs for use in calculating cumulative heat units at nest sites. Data from Gutzke and Packard (1987) and Ewert (1979). The threshold is determined by the intersection of the regression line with the x-axis; in this case it is 14°C. Note however that the threshold temperature is used only for the calculation of heat units and is not considered to have any biological relevance.

Figure 11b. An example of cumulative heat unit (HU) data from a nest-dummy nest pair. Cumulative heat units are an easy means of comparing thermal properties of different sites over time.


Y = -1.784 + 0.127 * X
R² = 0.906
DEVELOPMENT RATE (%/ d)
TEMPERATURE (deg C)
0
1
2
3
10
15
20
25
30
35


CUMULATIVE HEAT UNITS
DATE
250
225
200
175
150
125
100
75
50
25
0
30
4
9
AUG
19
HU NEST
HU DUM.

Appendix A. Body size and clutch size for adult female Blanding's turtles observed nesting in Nova Scotia between 1994 and 1996. There is no significant relationship between body size (PL) and clutch size (aCS max.) in this population.

Female Notch	Date Measured	CL cm	CW cm	PL cm	PW cm	Weight g	max kCS no. eggs
8-1,10	1995	18.90	13.50	17.70	9.90	940.0	—
8,0-9	24-May-95	22.20	15.00	20.50	11.60	1416.8	10
0-1	13-Jun-95	21.51	14.51	20.20	11.40	1425.0	—
3,3-3,4	24-Jun-95	21.00	13.70	20.65	11.00	1150.0	—
10-2	3-Jun-96	20.90	12.80	19.93	11.50	1200.0	9
0-1,8	16-Jun-96	20.00	13.70	19.20	10.40	1000.0	10
2,3-2	17-Jun-96	20.50	14.40	19.50	10.60	1150.0	11
0-1,3	22-Jun-96	20.00	13.40	18.80	10.10	950.0	12
9-3,11	22-Jun-96	21.00	14.20	20.10	10.70	1050.0	14
1-2	23-Jun-96	21.60	14.80	21.30	11.40	1200.0	11
0-10	24-Jun-96	20.40	14.50	19.80	10.70	1100.0	11
2,9-1,0	24-Jun-96	20.80	14.10	20.50	11.30	—	10
7,7-8,8	24-Jun-96	20.50	13.90	19.80	10.90	1300.0	10
9,0-11	24-Jun-96	20.90	14.90	20.20	10.90	—	11
0-3,8	27-Jun-96	19.90	14.20	19.60	11.00	1000.0	12
8-1,8	27-Jun-96	20.50	13.70	19.50	10.90	1050.0	8
8,0-3	29-Jun-96	19.10	13.10	18.30	11.00	900.0	7
8-1,3	30-Jun-96	22.30	15.10	21.80	11.70	1420.0	13

	CL	CW	PL	PW	Weight
n	18	18	18	18	16
sum	372.01	253.51	357.38	197.00	18252
mean	20.67	14.08	19.85	10.94	1140.74
STD	0.91	0.66	0.99	0.50	175.11
Max	22.3	15.1	21.8	11.7	1425
Min	18.9	12.8	17.7	9.9	900

Correlation: PL and max kCS

n	15
v	13
α	0.05
r	0.457
critical r	0.514

accept Ho. No significant relationship between body size and clutch size.

CL: carapace length; CW: carapace width
PL: Plastron length; PW: Plastron width

Appendix B. Nesting sequences of Blanding's turtles in Nova Scotia.

Nest ID #	Date nest was completed	Time female first observed	Time nest construction started	Time egg laying started	Time egg laying ended	Time nest burying ended	
1	15-Jun-94	2215				2300	
2	16-Jun-94						
3	18-Jun-94		2030			2250	
4	18-Jun-94	2140	<2140	2340	2355	0030	
5	18-Jun-94		2150			2330	
6	18-Jun-94		2038	2235	2301	2340	
7	18-Jun-94		2130	2216	2229	2320	
8	18-Jun-94		2130	2301	2311	2358	
9	19-Jun-94				2133	2250	
10	20-Jun-94	2122		<2226	2246	2330	
11	20-Jun-94	2120	2122	<2223	2236	2307	
12	22-Jun-94	2130	2130	2154	2216		
13	22-Jun-94	2159	2159		2250	2311	
14	23-Jun-94	2123	First seen while burying nest			2221*	
15	23-Jun-94	2142				>2242	
16	23-Jun-94	2135	2135	2140	2157	2230	
17	25-Jun-94				2200	2242	
NB	, but incorrect. Data book record: 2221 is correct						

Nest ID #	Date nest was completed	Time female first observed	Time nest construction started	Time egg laying started	Time egg laying ended	Time nest burying ended	
1	16-Jun-95			2048	2101	2130	
2	17-Jun-95	2030	2010	2105	2120		
3	18-Jun-95	2017					
4	19-Jun-95	2130			2145	2205	
5	19-Jun-95	2008	2030	2210	2214	2340	
6	20-Jun-95	2145		2345	0005		
7	22-Jun-95	2015	2055	2353	0007	0202	
8	23-Jun-95	2100			2112	2230	
9	24-Jun-95	2145					
10	24-Jun-95	1905	<2045	2112	2134		
11	25-Jun-95	2130			2215		
12	25-Jun-95	2130		2300	2316	0039	
13	25-Jun-95	1941	1952	2101	2114	2207	
14	26-Jun-95		1929	2215	2225	2314	
15	29-Jun-95	2025	2025			2150	
16	29-Jun-95	2027	2027		2130		

Nest ID #	Date nest was completed	Time female first observed	Time nest construction started	Time egg laying started	Time egg laying ended	Time nest burying ended	
1	12-Jun-96	2132		2244	2255	2350	
2	16-Jun-96	1900		<1940	1942	2041	
3	17-Jun-96	possibly at 1921	<2104		2107	2225	
4	20-Jun-96		1930	2130	2204	2330	
5	22-Jun-96	2055				2055	
6	22-Jun-96	2055		<2120	2143	2340	
7	22-Jun-96	2107	<2107	<2158	2213	2308	
8	23-Jun-96	2035	<2035	<2116	2133	2320	
9	23-Jun-96	2045	<2045	2142	2230	0058	
10	24-Jun-96	1820	<1820	<2034	2038	2208	
11	24-Jun-96	2130			<2140	2230	
12	24-Jun-96	2140	<2140	2220	2245	2330	
13	26-Jun-96						
14	27-Jun-96	2130				2130	
15	27-Jun-96					2235	
16	27-Jun-96	2025				2030	
17	28-Jun-96	2030			<2030	2129	
18	29-Jun-96	Female not observed. Nest uncovered with *C. picta* nest; *E. blandingii* nest ca. 24 hrs old.					
19	29-Jun-96				2030		
20	30-Jun-96	1955	2135	2330	235350	117	
21	3-Jul-96	Nest not found at excavation. Female was recorded nesting in borrow pit.					
22	5-Jul-96	2118	<2118		<2134	2236	

Appendix C. Clutch size and hatching success for Blanding's turtles in Nova Scotia.

Nest 1994		aCS	eCSh	Hatchlings emerged	% aCS emerged	Live excavated	%aCS live exc.	Dead excavated	%aCS dead exc.	Unhatched eggs	%aCS unhatched
1	P		10+	9		1					
2	P		15	8						7	
3	P		10	3		1		1		5	
4	P		11+	10		1					
5	P		10							2	
6	P	11		7	64%		0%	1	9%	3	27%
7	P	11		7	64%	3	27%	1	9%		0%
8	P	10		9	90%		0%		0%	1	10%
9	P	7		3	43%		0%	4	57%		0%
10	P	13		10	77%		0%		0%	1	8%
11	P	9		1+	Overwintered, but productive.						
12	P	12			No eggs or hatchlings found; assume productive, but exclude from n accounted for.						
13	P		14	9		2				3	
14	E				Overwintered. No excavation data available.						
15	E				Overwintered. No excavation data available.						
16	P	12		7	58%	5	42%		0%		0%
17	F	7			0%		0%		0%	7	100%

29 eggs failed (*i.e.* unhatched or dead excavation) in 13 productive nests: mean=2.2 eggs fail/productive nest

P Productive nest: produced at least one live hatchling.

F Failed or unproductive nest. No live hatchlings produced.

E Nest excluded from analysis of production.

aCS: absolute clutch size determined at nesting

eCSh: Clutch size estimated from hatching and excavation data

Summary: 1994

No. nests with aCS	9	
Mean clutch size (aCS)	10.2	
SD	2.2	
No. protected nests:	17	
No. protected nests excluded	2	Overwinter

No. known productive nests	13	
No. nests assumed productive	1	
No. productive nests	14	
% productive nests	14/15	93%
No. successfully protected, but failed:	1/15	7%

Category	**Total accounted for**	**From n nests**	% Total	
Emerged	83	12	62.9%	Excluded 3 overwintered nest for which excavation data are unavailable.
Live exc.	13	6	9.8%	
Dead exc.	7	4	5.3%	
Unhatched	29	8	22.0%	
Total:	132			
Total- eggs	103			
Dead exc.	7		6.8%	

Nest 1995		aCS	eCSh	Hatchlings emerged from nest	% aCS emerged	Live excavated	%aCS live exc.	Dead excavated	%aCS dead exc.	Unhatched eggs	%aCS unhatched
1	P	10		5+		1	10%		0%	1	10%
2	P	14		9	64%	1	7%		0%	4	29%
3	E		4+		Nest predated during incubation season						
4	P		11	10						1	
5	P	14		3+		3	21%	1	7%	1	7%
6	P		4+	2 +							
7	P	10		3	30%	4	40%	2	20%	1	10%
8	P		13	11		2					
9	P		10	10							
10	P	12		8	67%	2	17%		0%	2	17%
11	P		15	13		2					
12	P		11	9		1				1	
13	P	10		6+		1	10%		0%	2	20%
14	P	10		10	100%		0%		0%		0%
15	F	5			0%		0%		0%	5	100%
16	P		5+/-		Signs of emergence, but hatchling(s) likely escaped; thus are not accounted for (see summary).					3	

19 eggs failed (*i.e.* unhatched or dead excavation) in 14 productive nests: mean = 1.4 eggs fail/productive nest

P Productive nest: produced at least one live hatchling. **aCS: absolute clutch size determined at nesting**

F Failed or unproductive nest. No live hatchlings produced. **eCSh**: Clutch size estimated from hatching and excavation data

E Nest excluded from analysis of production.

NB nest 5(95): Only 3 accounted for live emerged, though aCS=14. Excavation data suggest the 6 unnaccounted for were live emerged.
Three (3) were road kill, expected 1 found in spring 96 was from this nest.

Summary: 1995

No. nests with aCS	8
Mean clutch size (aCS)	10.6
SD	2.9

No. protected nests:	16	
No. protected nests excluded	1	Predation
No. productive nests	14/15	93%
No. successfully protected, but failed:	1	7%

Category	Total accounted for	From n nests	% Total
Emerged	99	13	70.7%
Live exc.	17	9	12.1%
Dead exc.	3	2	2.1%
Unhatched	21	10	15.0%
Total:	140		
Total- eggs	119		
Dead exc.	3		2.5%

Nest 1996		aCS	eCSh	Hatchlings emerged from nest	% aCS emerged	Live excavated	%aCS live exc.	Dead excavated	%aCS dead exc.	Unhatched eggs	%aCS unhatched	Flooded?
1	F	9								9	100%	Yes
2	F	10						10	100%		0%	Yes
3	P		8	5		2			0%	1		No
4	F	15				Poor drainage on roadside = flooded				15	100%	Likely
5	F	10								10	100%	Yes
6	P	14				11	79%		0%	3	21%	No
7	F	10						4	40%	6	60%	Yes
8	P	11				9	82%		0%	2	18%	No
9	P	11		11	100%						0%	No
10	F	10								10	100%	No
11	P	11		11	100%							No
12	F	11								11	100%	Yes
13	P	7				5	71%			2	29%	Likely
14	F	8								8	100%	Yes
15	P	12				8	67%		0%	4	33%	No
16	P*	9		Nest flooded		7	78%			2	22%	Yes
17	P	12	7/9 hatched died by Dec 25			9		1(died 1/2 emerged)		2	17%	No
18	F	9								9	100%	Possibly
19	F	4								4	100%	Yes
20	P	12				10	83%			2	20%	Unlikely
21	E		UNK	Female seen, but nest not located at excavation. Borrow pit.								
22	F	10								10	100%	Yes
23	P		3+			2	Not protected.			1		No
UNK	E			1	One hatchling discovered wandering on beach, likely from nest 23.							

20 eggs failed (*i.e.* unhatched or dead excavation) in 11 productive nests: mean=1.8 eggs fail/productive nest

P Productive nest: produced at least one live hatchling.

F Failed or unproductive nest. No live hatchlings produced.

E Nest excluded from analysis of production.

* flooded nest was excavated and incubated indoors.

aCS: absolute clutch size determined at nesting

eCSh: Clutch size estimated from hatching and excavation data

Summary: 1996

No. nests with aCS	20	No. protected nests:	22	
Mean clutch size (aCS)	10.3	No. protected nests excluded:	1	Nest 21 not located
SD	2.4	Additional nests:	1	

No. protected nests that were productive	10	
No. known productive nests	11	include nest 23 that was not protected, but was productive.

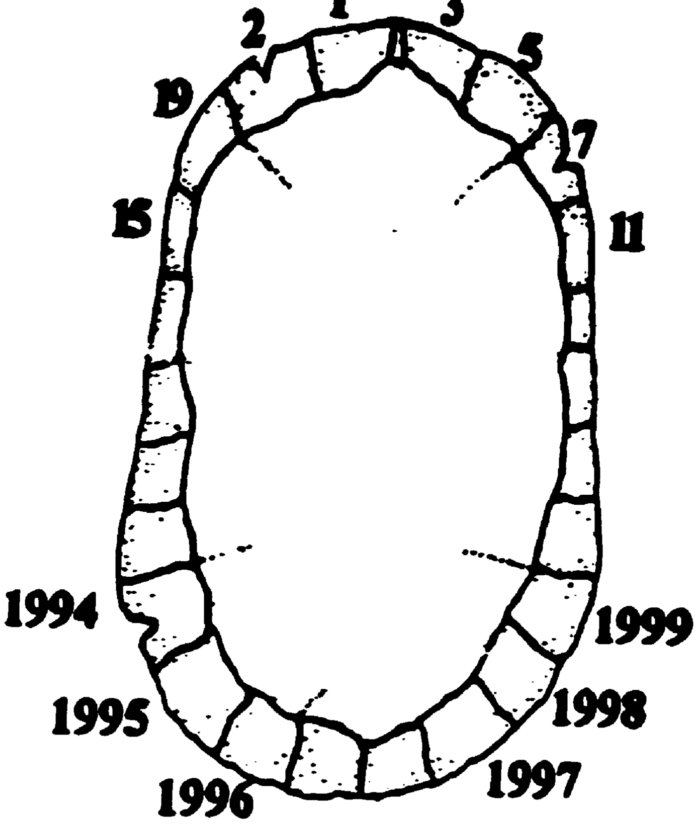
% productive nests	11/22	50%

Category	**Total accounted for**	**From n nests**	**% Total**	
Emerged	27	3*	12.9%	(excludes single hatchling found on beach)
Live exc.	63	9	29.0%	Includes eggs excavated that later hatched.
Dead exc.	15	3	6.9%	
Unhatched	111	19	51.2%	

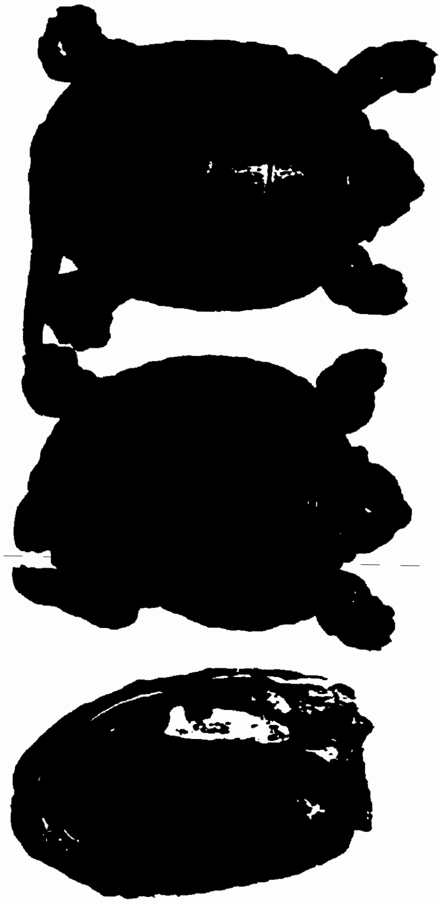
* assume one hatchling from unknown nest was from nest 23

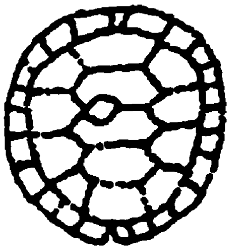
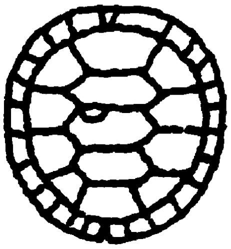
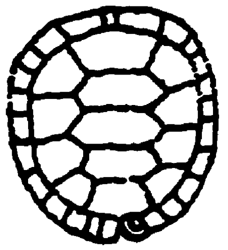
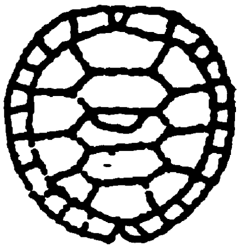
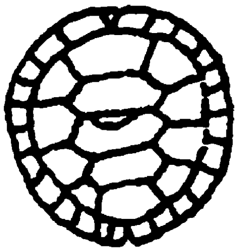
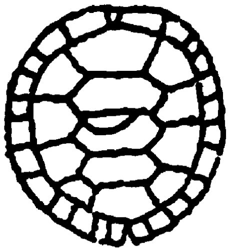
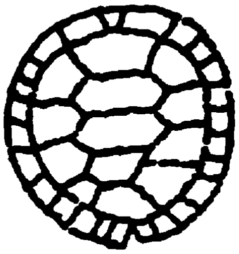
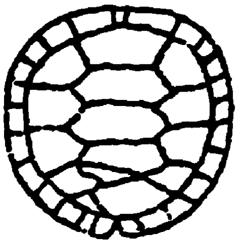
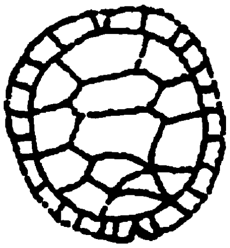
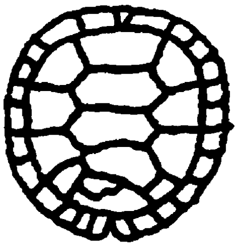
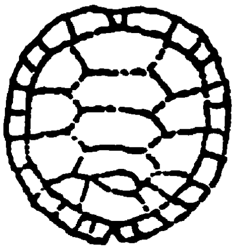
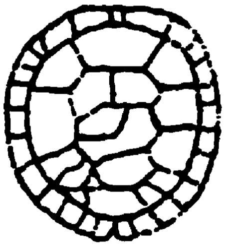
Total:	216		
Total- eggs	105		
Dead exc.	15		14.3%

Appendix D. Hatchling notching system. Adapted from Standing *et al.* (1995). This system is used to identify neonates to their nest of origin and their mother. It is a semi-permanent means of identification; as turtles grow the notches become less visible. At around 6 cm (carapace length) the turtle is given a unique notch code according to the adult notching sytem after Power (1989). Notches are made in the marginal scutes of the carapace with nail clippers. Anterior scutes of the carapace encode the nest of origin (see Chapter 1) (*i.e.* add the notches). Posterior scutes encode the year of oviposition which is also the year of hatchling emergence. Hatchlings are given a maximum of three notches. The hatchling in this example emerged in 1994 from nest 9 (*e.g.* notches 2 + 7) (or nest 9(94)).

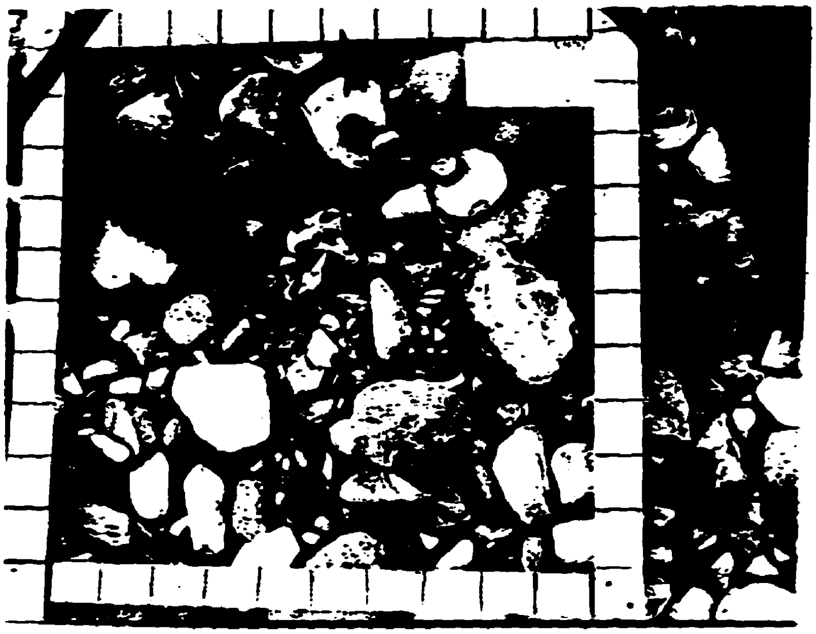

1
2
3
5
19
7
15
11
1994
1999
1995
1998
1996
1997

Appendix E. Developmental abnormalities observed in neonate Blanding's turtles in Nova Scotia.

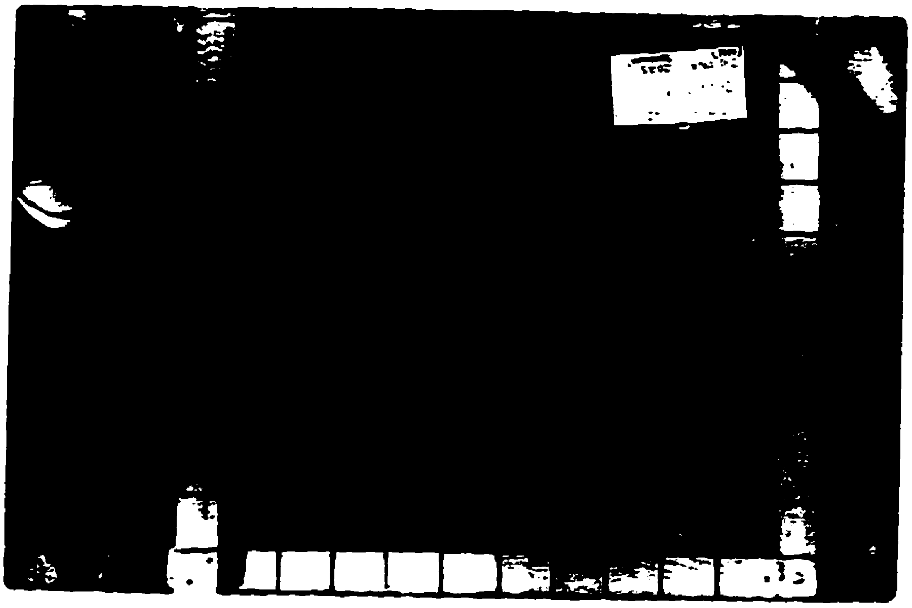


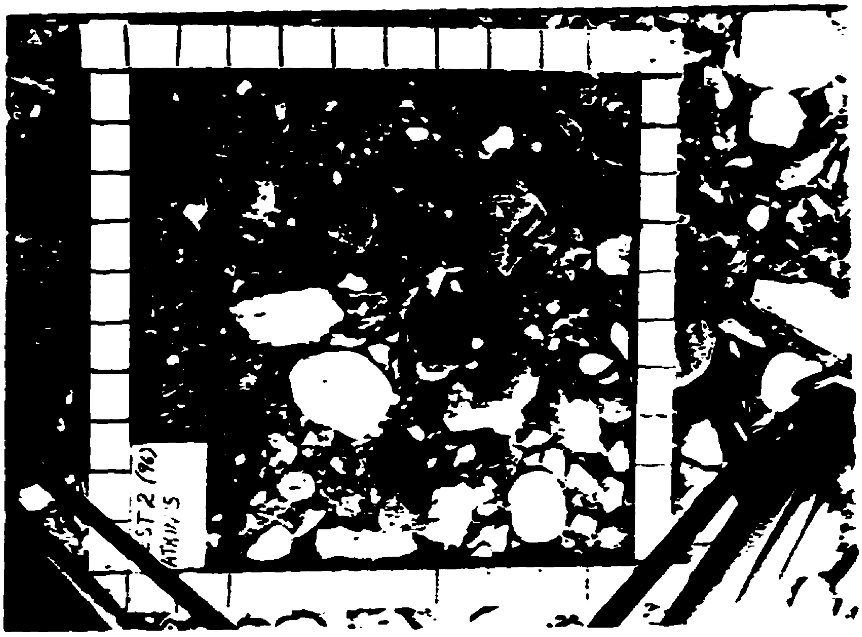













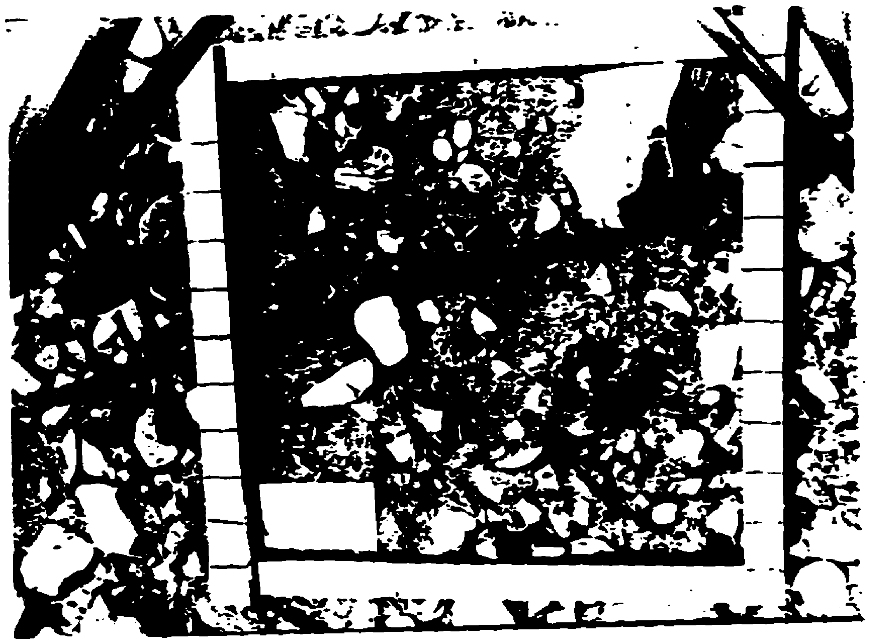
Appendix F. Photographic analysis of nesting substrates. Blanding's turtles in Nova Scotia nest in coarse material relative to populations elsewhere, but the variety of substrates in which these turtles dig, and successfully complete nests does not suggest that surface substrates are used by females as cues in determining the suitability of a site. The first two photographs (page 158) are sites in which turtles were digging, but did not complete nests; all other photos are surfaces of actual nest sites throughout Kejimkujik National Park, Nova Scotia. The area within the square frame is 50 cm^2.

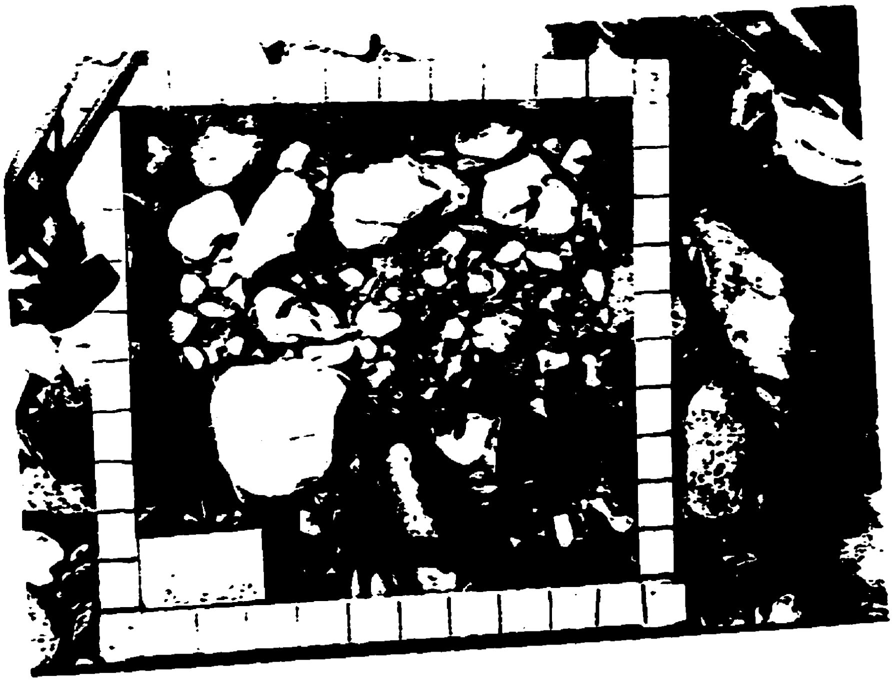


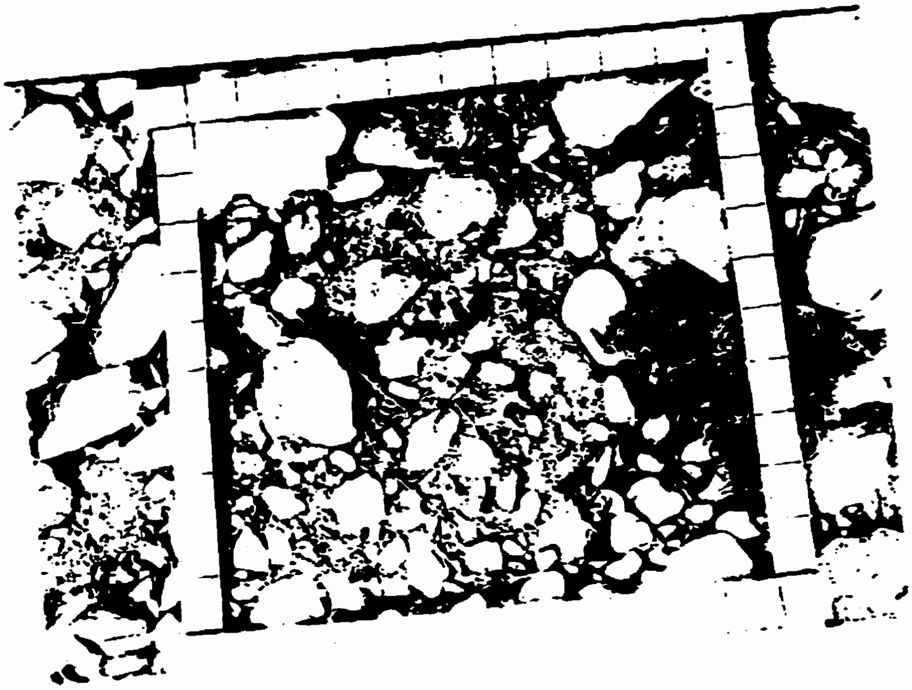
f

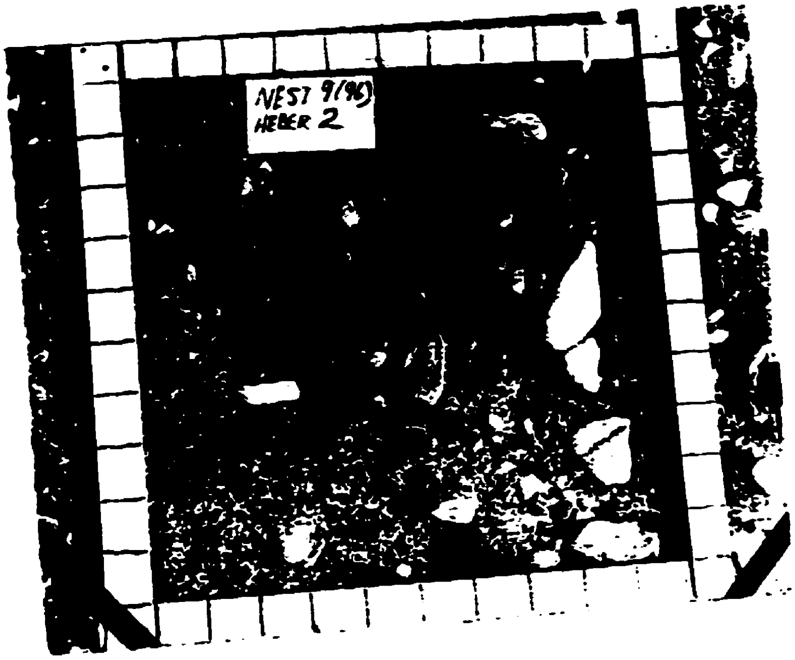



ST 2 (96)
ATKINS

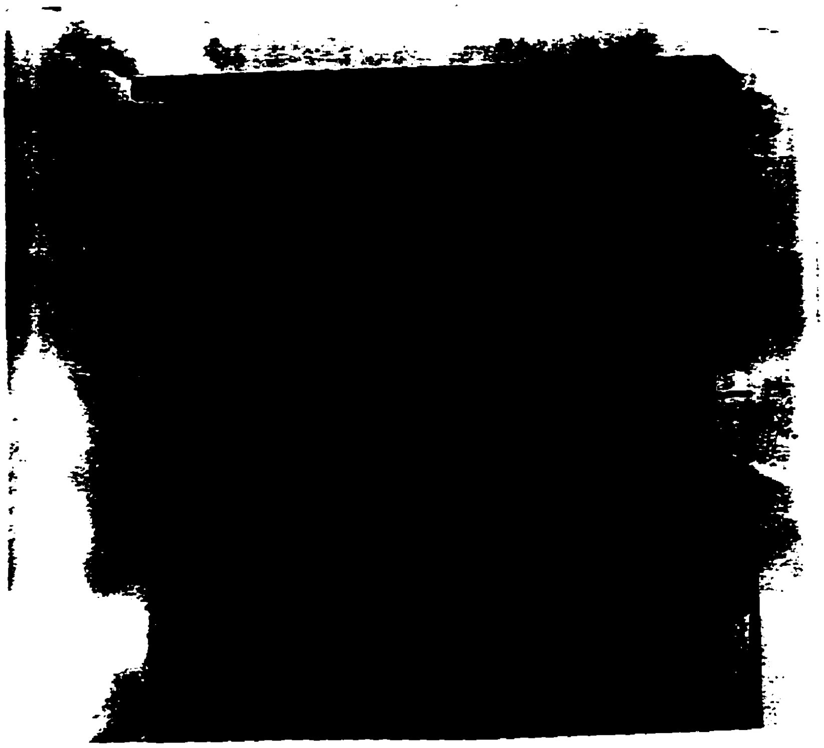


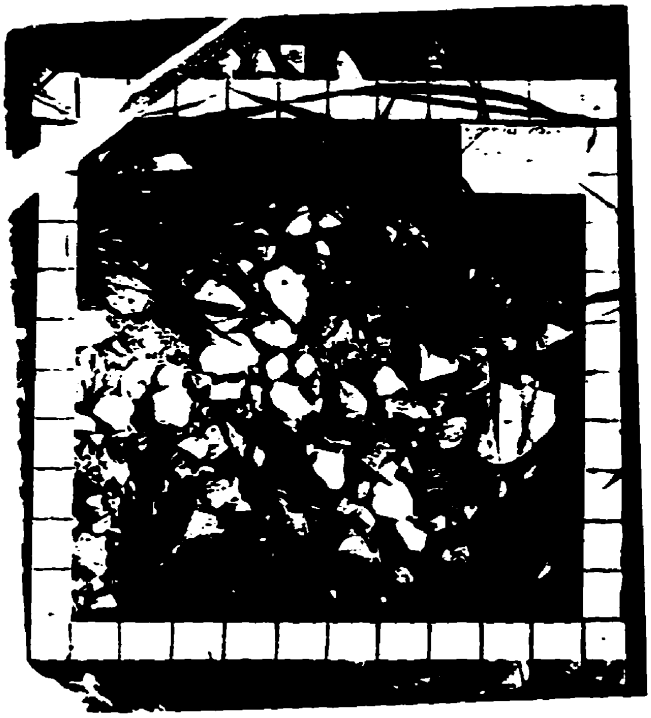




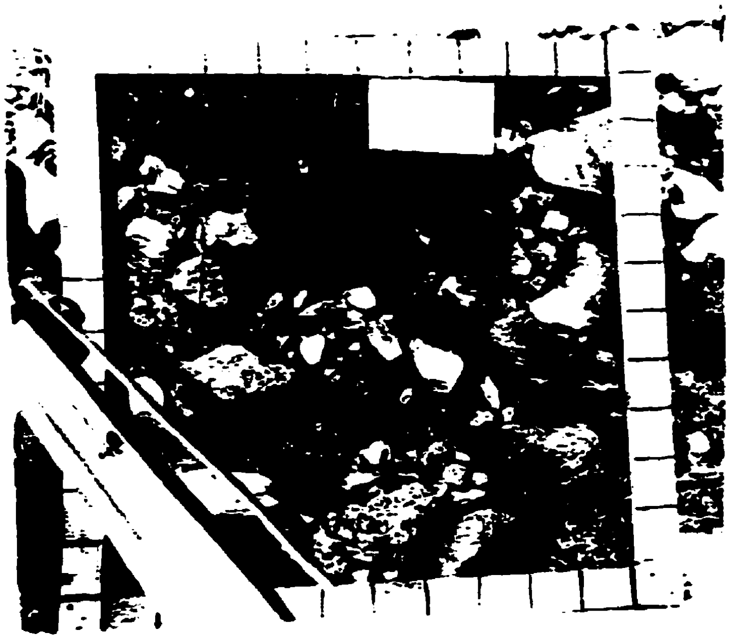

NEST 9(96)
HEBER 2


NEST 11(96)
ATKIN'S






NEST
GLIDE




NEST 15 (96)
GECOS ISLAND


NEST 18 (96)
ATKINS 2

Appendix G.

Apparent depredation of Blanding's turtle (*Emydoidea blandingii*) neonates by short-tailed shrews (*Blarina brevicauda*).

Blanding's turtle (*Emydoidea blandingii*) is a North American, fresh water species with a range centered south of the Great Lakes (Herman et al., 1995). Isolated populations occur outside the main range in Wisconsin (Ross, 1989), Massachusetts (Butler and Graham, 1995), Minnesota, New Hampshire, New York and Nova Scotia (Herman et al., 1995). The species is considered threatened in Nova Scotia (Herman et al., 1995) and recent research is being applied to the development of conservation strategies appropriate for this population (Herman et al., submitted).

Like many turtles, Blanding's turtles are long-lived (Brecke and Moriarty, 1989; Congdon and van Loben Sels, 1993; Herman et al., 1995), have delayed sexual maturation (McMaster, 1996; Congdon et al., 1993; Petokas, 1986), and are vulnerable to increases in juvenile and adult mortality (Congdon et al., 1993; Iverson, 1991). The scarcity of sexually immature turtles in the Nova Scotia population, and the low recruitment into its breeding population (Herman et al., 1995) have lead to the implementation of a headstarting programme (Herman et al., submitted).

To date, most 'headstarting' in this population consists of nest protection, although an experimental evaluation of the captive rearing and release of 'headstarted hatchlings' is currently underway. Since the objective of hatchling headstarting programmes is to raise neonates to a size sufficiently large to reduce their vulnerability to depredation, the identification of predator species is crucial. Such information will help managers determine the minimum size requirements necessary for an effective headstarting programme. We report observations on the depredation of neonate Blanding's turtles (*Emydoidea blandingii*) by short-tailed shrews (*Blarina brevicauda*) in Kejimkujik National Park, Nova Scotia, Canada.

Methods and Results. - Data were collected in 1994 and 1995 during a study of the early post-emergence behaviour of neonates in this population (Standing et al., in press). Detailed descriptions of the study site are available elsewhere (Standing et al., in press; McNeil, 1996; McMaster, 1996; Herman et al., 1995; Power et al., 1994; Power, 1989).

During the nesting season (June and July) of 1994 and 1995, 23 freshly laid Blanding's turtle nests were protected against depredation. Each nest was covered with a 50 cm^2 raised box-frame screened with one inch hardware cloth. These screened boxes effectively guarded against depredation of eggs, and served as pens for emergent hatchlings. Hatchling emergence was mostly asynchronous (occurring over several days), occurring throughout September and October. Hatchlings emerged during the day and were diurnally active. Upon emergence, numerous hatchlings were measured, weighed, powdered with tracking-pigment, and tracked from 1 to 11 days (Standing et al., in press). Most hatchlings were released on the day of emergence, although some hatchlings spent their first night in the enclosures.

After release, hatchlings used terrestrial and aquatic forms (sleeping and resting sites) both during the day, and overnight. Usually, while in terrestrial forms, neonates were well concealed beneath vegetation and roots, or between beach cobble; sometimes, hatchlings remained on the beach overnight, completely exposed (Standing, 1997; Standing et al., in press; McNeil, 1996).

In 1994, five hatchlings from two nests were found dead at the end of their trails. Four of these were nestmates and were found dead near the nest box during the day shortly after their release. At the time of their release, these hatchlings were severely bitten by ants; since the corpses were intact, presumably, these died from ant bites; they were later scavenged by unidentified animals. A fifth hatchling, from the second nest, was released at 1322 hrs on Sept. 25, and was depredated at night (ca. 2200 hrs) shortly after having been located alive at the end of its trail. Although no carcass was found, we heard the predator emerge from nearby shrubbery, and concluded that, in this instance, the turtle was depredated by a medium-sized mammal, possibly a raccoon. While in the screened-enclosures, four additional, unpowdered hatchlings from three nests were depredated; two others had signs of attempted depredation (i.e. superficial bites taken from their shells), but survived.

In 1995, eviscerated carcasses of four hatchlings were found at, or near the end of their trails on Sept. 19, 22, 23 and 25, respectively. These hatchlings had been nestmates, and were within 20 m of the nest site at the time of depredation; depredation occurred up to 6 days after release. Three additional, unpowdered hatchlings from this nest were depredated from under the protective screen on Sept. 19, 20 and 23. On Sept. 19, after having found one eviscerated corpse in the enclosure, observers interrupted the predator while it ate one of the released, powdered hatchlings (ca. 2040 hrs). In handling this hatchling the predator was covered in pigment, and its trail was followed for a short distance. Footprints were discernible, and were identified as those of the short-tailed shrew (*B. brevicauda*).

The most prevalent style of mutilation was evisceration. Typically, a section of the plastron was removed (eaten) beginning at the axillary scutes, proceeding medially to the midline suture of the abdominal scute, and dorsally to the inguinal region. Otherwise, a central disk radiating from the umbilical region was removed. Hatchling were also eviscerated through the carapace. Either a circular area centered on the suture between the second and third vertebral scutes and extending laterally to the middle of adjoining costal scutes was removed, or a crescent extending medially from the axillary and inguinal regions was removed. Two hatchlings were decapitated, and one that had been eviscerated through the plastron also had had the skin and foot removed from its left hind leg. Those hatchlings that survived attempted depredation had bites taken from the marginal scutes 5, 6 and 7 (after Pritchard, 1979), and from the carapace.

Discussion. - Turtles, including Blanding's turtle, have been characterized as having a Type III survivorship curve in which the rate of mortality is inversely related to age (Iverson, 1991). Presumably, this results from intense depredation on early life stages, particularly of eggs (Iverson, 1991). In fact, numerous authors have attributed high clutch failure in freshwater turtles (*Chelydra serpentina, Chrysemys picta, Clemmys insculpta* , *Emydoidea blandingii, Kinosternon flavescens*) to depredation by raccoons (*Procyon lotor*), skunks (*Mephitis mephitis*), foxes (*Vulpes fulva* and *Urocyon cinereoargenteus*), badgers (*Taxidea taxus*), hognose snakes (*Heterodon nasicus*), rodents, and small, unidentified mammals (Herman et al., 1995; Brooks et al., 1991; Iverson, 1989; Ross and Anderson, 1990; Petokas, 1986;

Power, 1989; Congdon et al., 1983). While nest screening programmes such as that implemented in Nova Scotia improve clutch survival, these programmes are insufficient conservation measures (Heppell et al., 1996). Threatened populations would benefit from the protection of sexually immature turtles in the wild, and the headstarting of hatchlings (Heppell et al, 1996; Iverson, 1991).

It is widely accepted that, in addition to eggs, small turtles are likely most vulnerable to depredation pressure. Since this is the underlying premise of headstarting programmes (Heppell, 1996), the design of effective management strategies requires a thorough knowledge of causes of mortality in small size classes.

Our evidence suggests that the short-tailed shrew (*B. brevicauda*) should be added to the growing list of predators of small freshwater turtles. To date, confirmed predators include gulls (*Larus* spp.), crows (*Corvus* spp.) raccoons (*Procyon lotor*), bullfrogs (*Rana catesbeiana*) (Lefevre and Brooks, 1995), water snakes (*Nerodia* sp.) (Janzen et al., 1992), coyotes (*Canis latrans*) (Minckley, 1966), and larger turtles (Sloan et al., 1996); putative predators include dogs, cats, toads, bears (Ehrenfeld, 1979), squirrels (McNeil, pers. comm.), mink, otter, wading birds, and large, predatory fish (Congdon et al., 1992).

Short-tailed shrews (*B. brevicauda*) are common throughout Nova Scotia. They are opportunistic predators that primarily feed on invertebrates, though they have been known to catch and eat small lizards and mammals (Churchfield, 1990), and it is not unreasonable to suspect them of being able to eat small, hatchling Blanding's turtles, especially since the shells of neonate turtles are not heavily calcified. Though the foraging of *B. brevicauda* tends to be undirected, shrews will return to a concentration of prey until the supply is exhausted (Churchfield, 1980); this would explain the apparent exploitation of individual nests in our study. In addition to the style of mutilation, and the observed footprints, other evidence suggestive of shrews is that they are small enough to fit through one inch hardware cloth; that is, without disturbing or digging beneath the screened-boxes, shrews could have accomplished the observed depredation of hatchling in the enclosures.

As well as providing necessary information for the development of effective headstarting programmes, the identification of species that prey on hatchling freshwater turtles can provide insight into their antipredator mechanisms (Briston and Gutzke, 1993), behaviours (Butler and Graham, 1995; Lefevre and Brooks, 1995; Janzen et al., 1992), and habitat selection (Congdon et al., 1992; Pappas and Brecke, 1992). Combined, such information will help in the development of comprehensive management plans for the protection of young, vulnerable size classes in the wild.